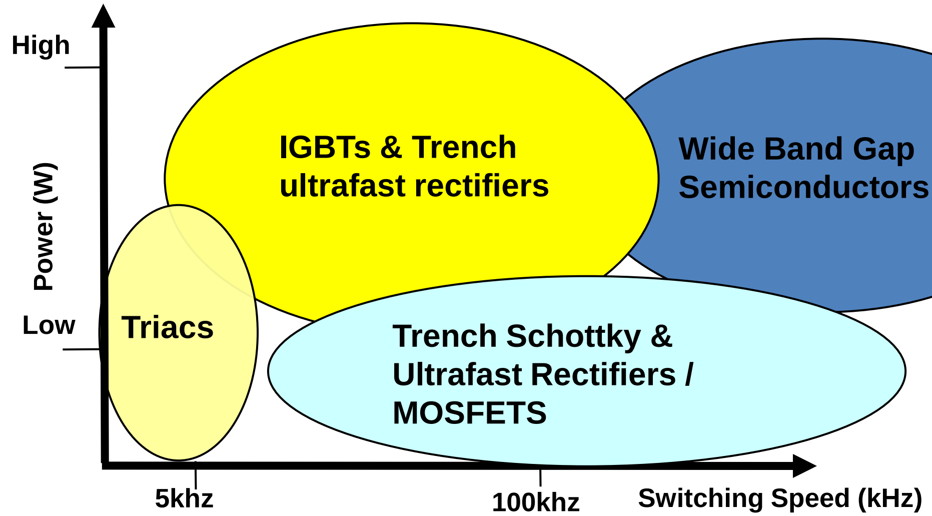
Vision Series:
Overview and Design Guidelines for Power Discrete Technologies

ON Semiconductor®

Power Management

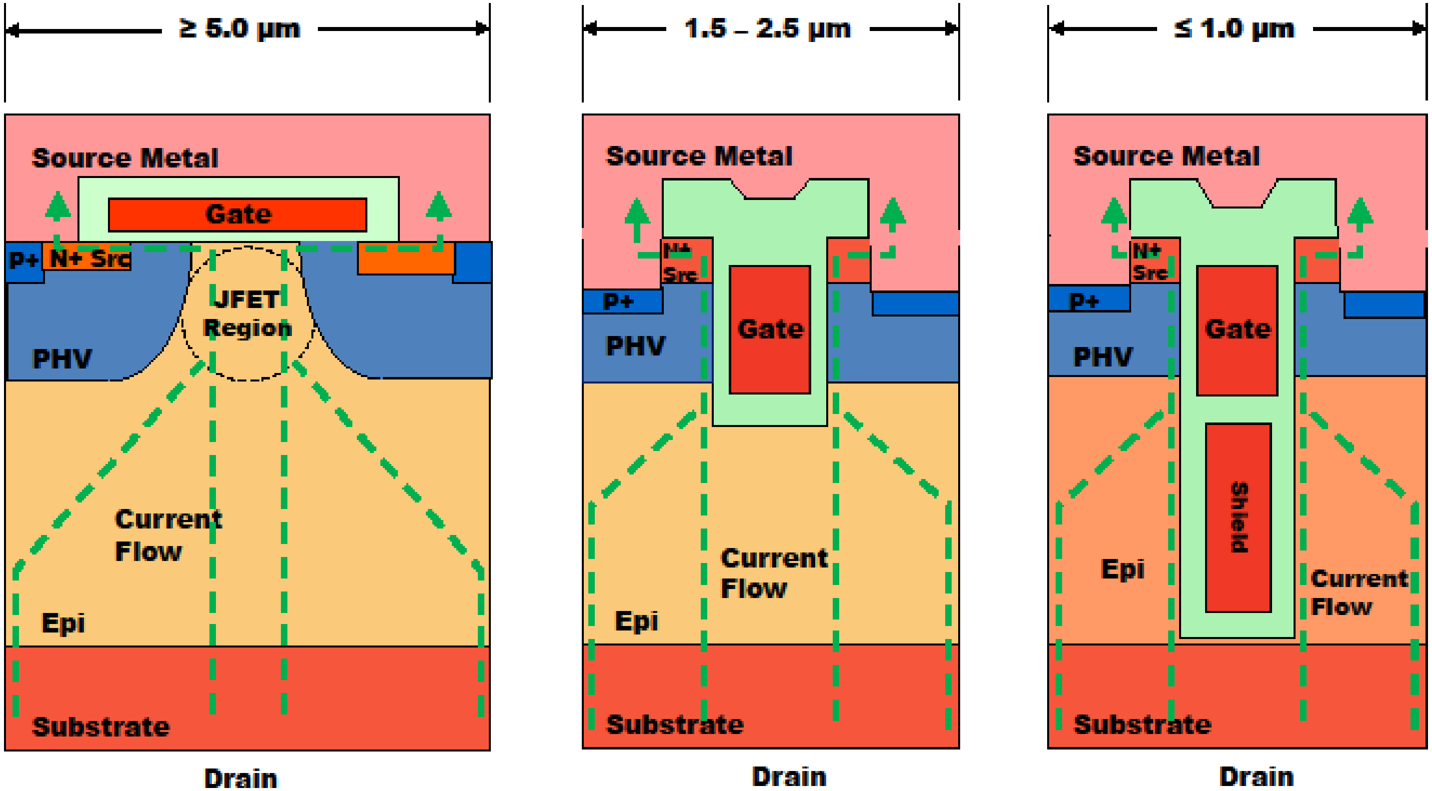
Five Years Out

Power Discretes Technology & Frequency



- **Switching Frequency (50hZ to ≤ 5kHz); Low to Medium power**
  - Applications: Relay solenoid drivers, auxiliary controls, Motor control
  - Power Discretes: Triacs
- **Switching Frequency (≥50kHZ up to MhZ), Low Power = ≤ 1kW**
  - Applications: Power Supplies
  - Power Discretes: MOSFETs, Trench ultrafast rectifiers, Trench Schottky rectifiers
- **Switching Frequency (5kHZ to 100kHZ); High Power ≥ 1kW**
  - Applications: Motor controls, White Goods appliances, Solar & Wind power, UPS
  - Power Discretes: IGBTs, Ultrafast rectifiers
- **Switching Frequency (> 100kHZ), High Power ≥ 1kW**
  - Applications: HEV, Solar & Wind inverters, Power supplies, UPS
  - Power Discretes: SiC or GaN Diodes and Transistors

MOSFET Structure

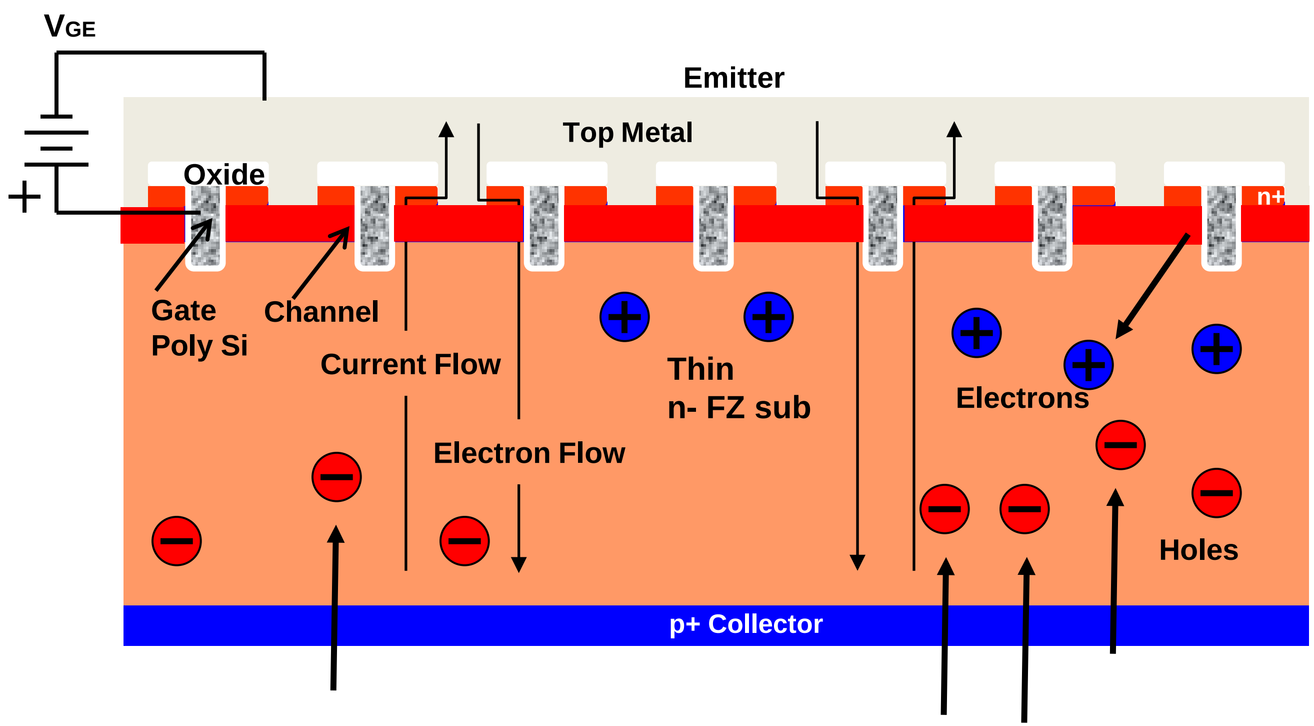


Planar MOSFET
- Channel is horizontal.
- Cell pitch ≥ 5um.
- High Rdson, due to low channel density, and JFET region.

Trench MOSFET
- Channel is vertical
- Cell pitch 1.5 – 2.5um.
- Lower Rdson, due to high channel density, and no JFET region.
- High capacitance. Thick oxide may be used at trench bottom to reduce Cgd.

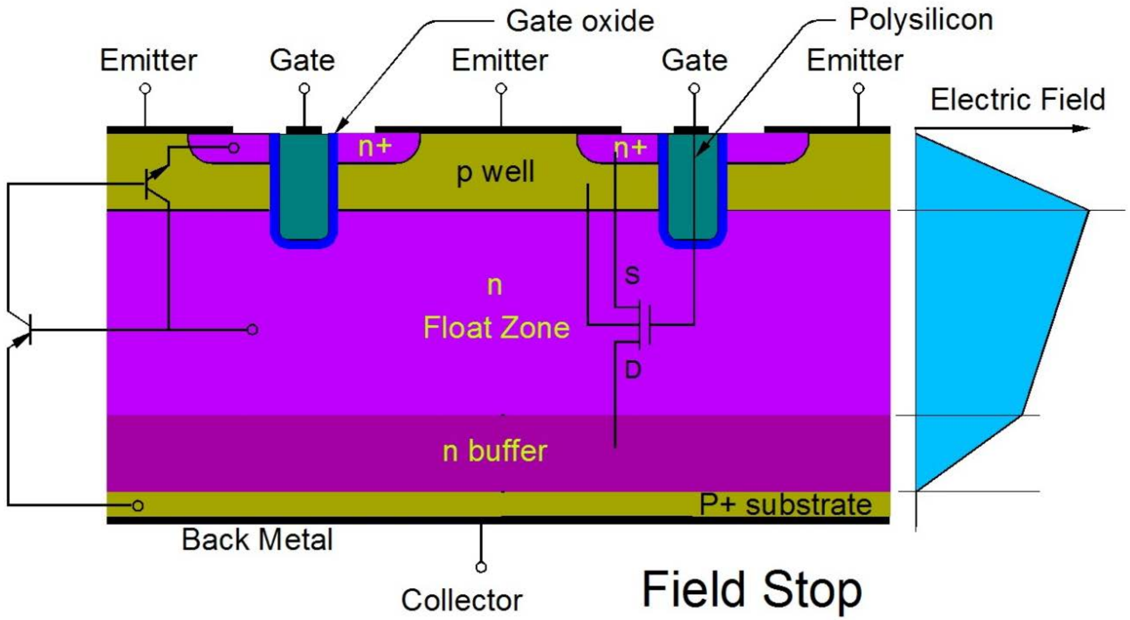
State of the Art Trench MOSFET
- Channel is vertical
- Cell pitch ≤ 1um.
- Shield electrode enables higher epi doping concentration, as well as lower Cgd.
- Ultra-low Rdson, due to very high channel density, and high epi doping.

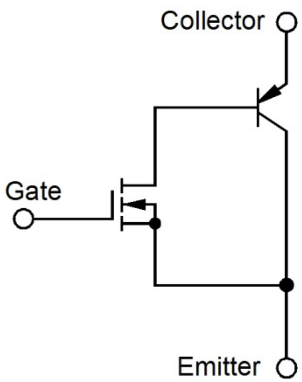
IGBT Current Flow



- Similar to a power MOSFET but substrate is p+ instead of n+, forming a diode on the backside
- First the channel is formed by applying +ve voltage on the gate, allowing electron flow downward
- The back p+ /n-FZ sub junction is forward biased and holes are injected into the n-FZ sub
- The high concentration of holes and electrons in the n float zone reduce the bulk resistance by 10x
- Switching is slowed because the holes die slowly after the channel is cut off

IGBT Structure with Parasitic BJTs





- **n-channel FET with P+ diode (substrate) connection**
- **pnp high current BJT**
- **npn parasitic BJT with BE junction shorted**
- **Was initially designed to be a MOS gated SCR**

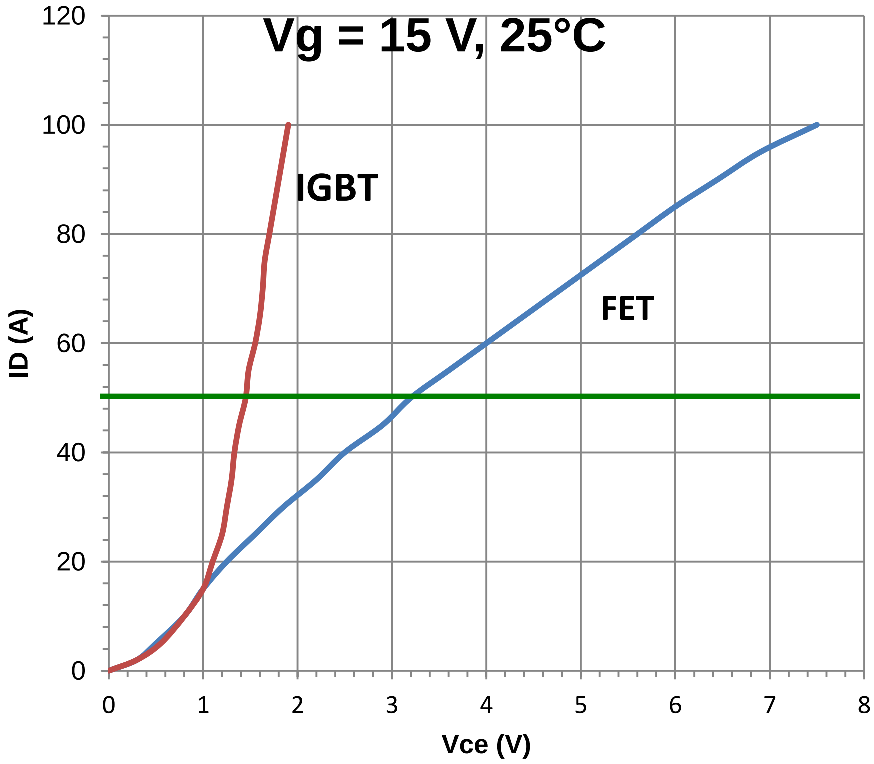
Use of MOSFETs vs. IBGTs

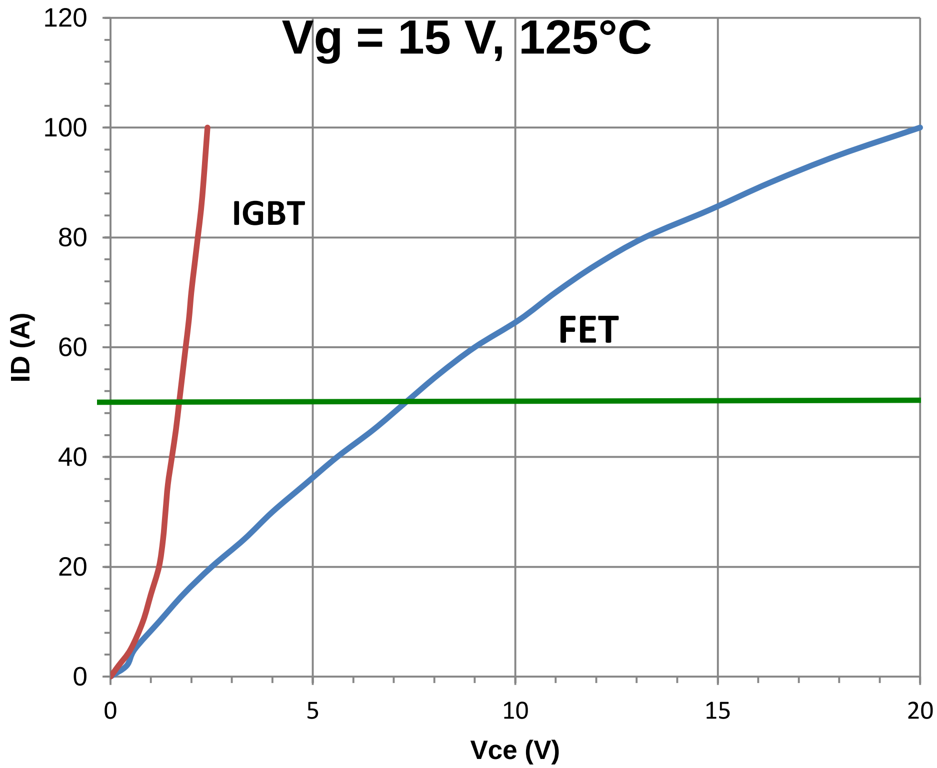
Use of MOSFETs vs. IGBTs

MOSFETs	IGBTs
V_{DS} 10 – 1500	V_{CE} 300 – 6500 V_{CE}
I_D ≦ 300 A (discretes)	I_D ≤ 150 A (discretes)
I_D ≤ 600 A (modules)	I_D ≤ 2000 A (modules)
tr 10 ns – 70 ns	tr 20 ns – 150 ns
tf 10 ns – 90 ns	tf 30 ns – 250 ns
Typ sw freq 100 – 500 kHz	Typ sw freq 20 – 70 kHz
≥ 1MHz for integrated drivers	
t_{Jmax} 150 °C – 175 °C	t_{Jmax} 150 °C – 175 °C

Use of MOSFETs vs. IGBTs

Comparison of V_{CE}, V_{DS} for 600 V, 50 A parts





Infineon IPW60R070C6 CoolMOS 600 V, 53 A MOSFET

ON Semiconductor NGTG50N60FW 600 V, 50 A IGBT

Effects of Switching Frequency

Benefits of high switching frequencies

- Reduction of transformers for isolated converters
- Reduction of LC filter elements

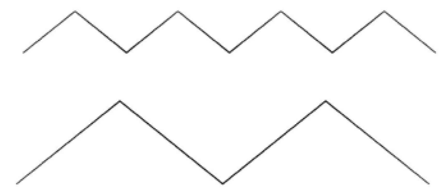
Benefits of lower switching frequencies (above audible)

- Lower EMI
- Reduction of switching losses
- No magnetic/capacitor advantage for motor drives due to high motor inductance

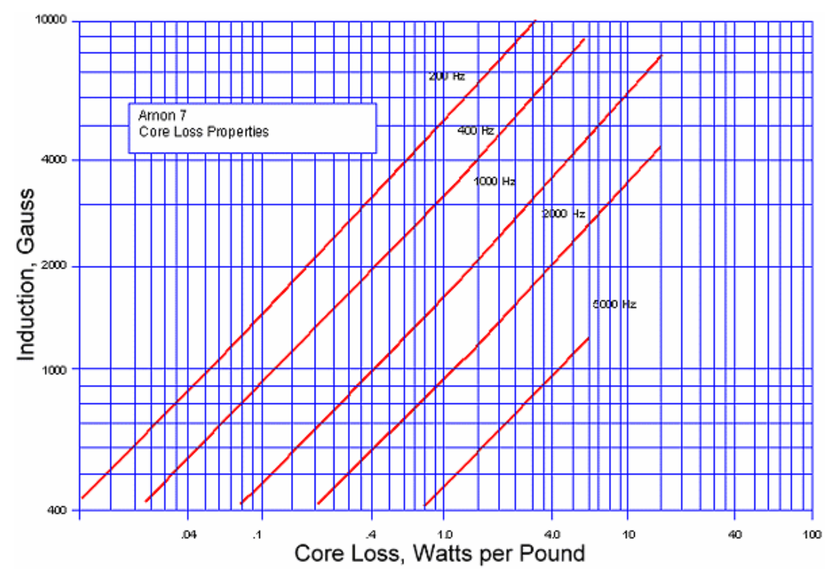
Effects of Switching Frequency for Motors

What are the effects on a motor as the switching frequency varies?

For a given inductance, a higher switching frequency will cause a lower ripple current at that frequency which will reduce the ac flux levels for the switching frequency. This supports a higher switching frequency.



The core losses of the motor increase with frequency and this supports a lower switching frequency.



So which is it?

Effects of Switching Frequency for Motors

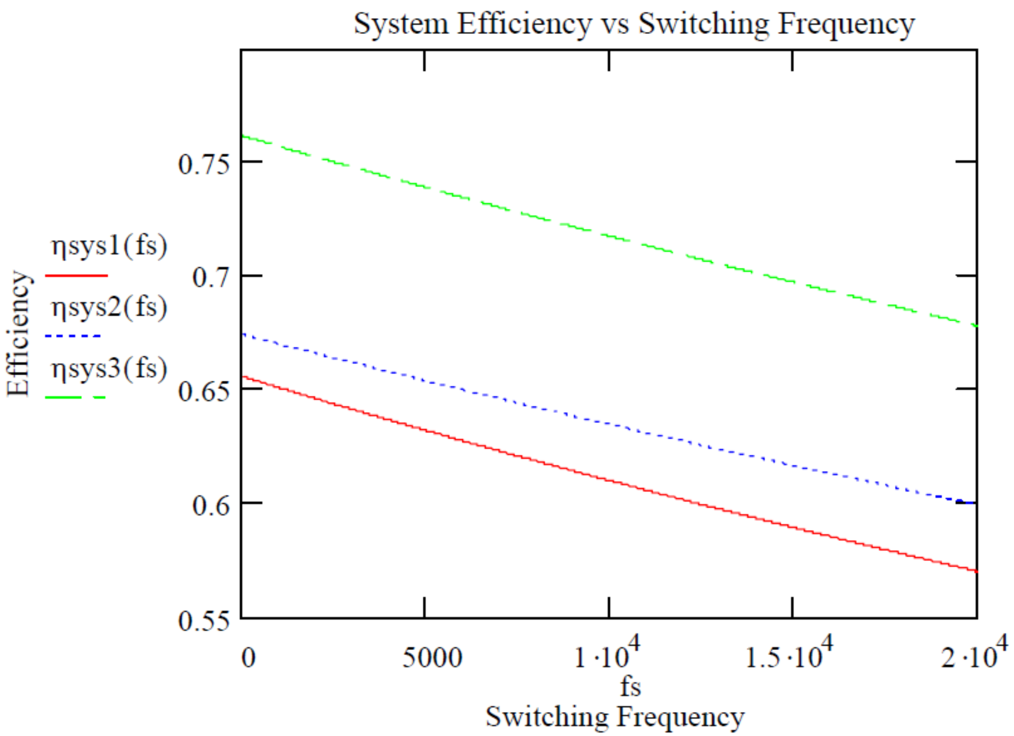
This chart shows the efficiency dropping as the switching frequency is increased.

Sys1 – 60 in-lb

Sys2 – 120 in-lb

Sys3 – 180 in-lb

2000 rpm



Source: Switching Frequency Effects on Traction Drive System Efficiency, William L. Cornwell, Virginia Polytechnic Institute, Sept.6, 2002

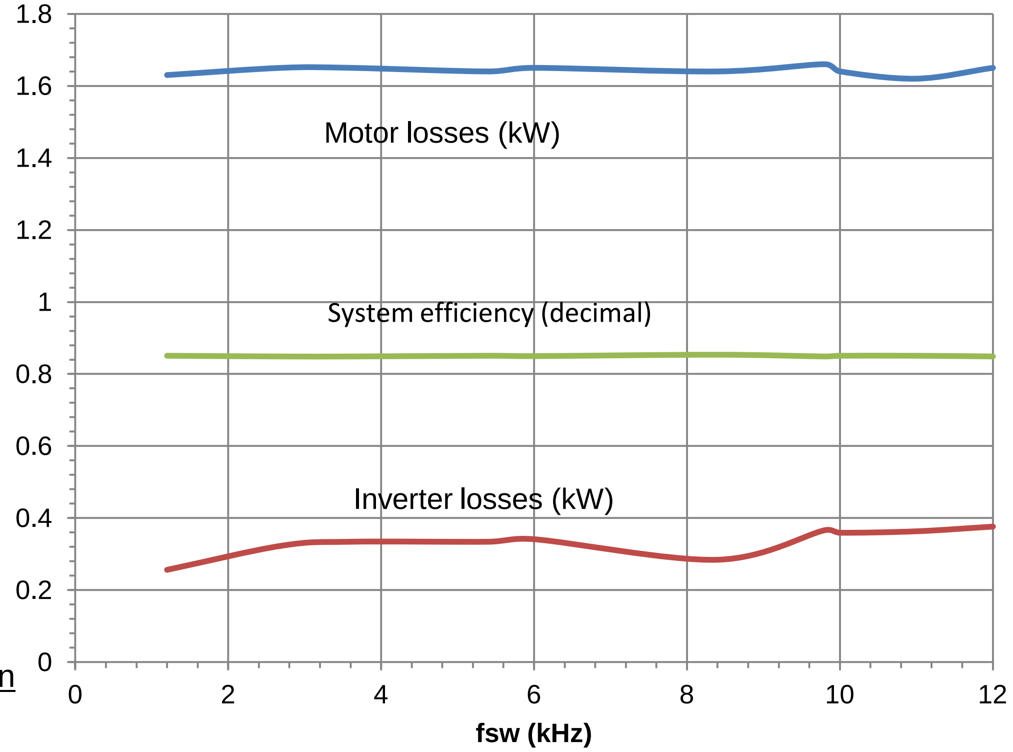
Effects of Switching Frequency for Motors

This study shows no significant difference based on the switching frequency.

Induction motor

50 Hz fundamental frequency

75 Nm load



Source: Influence of Switching Frequency and Squirrel Cage Design on Audible Noise and Losses in Induction Motor Drives, S. Van Haute, A. Malfait, R. Belmans, Katholieke Universiteit Leuven

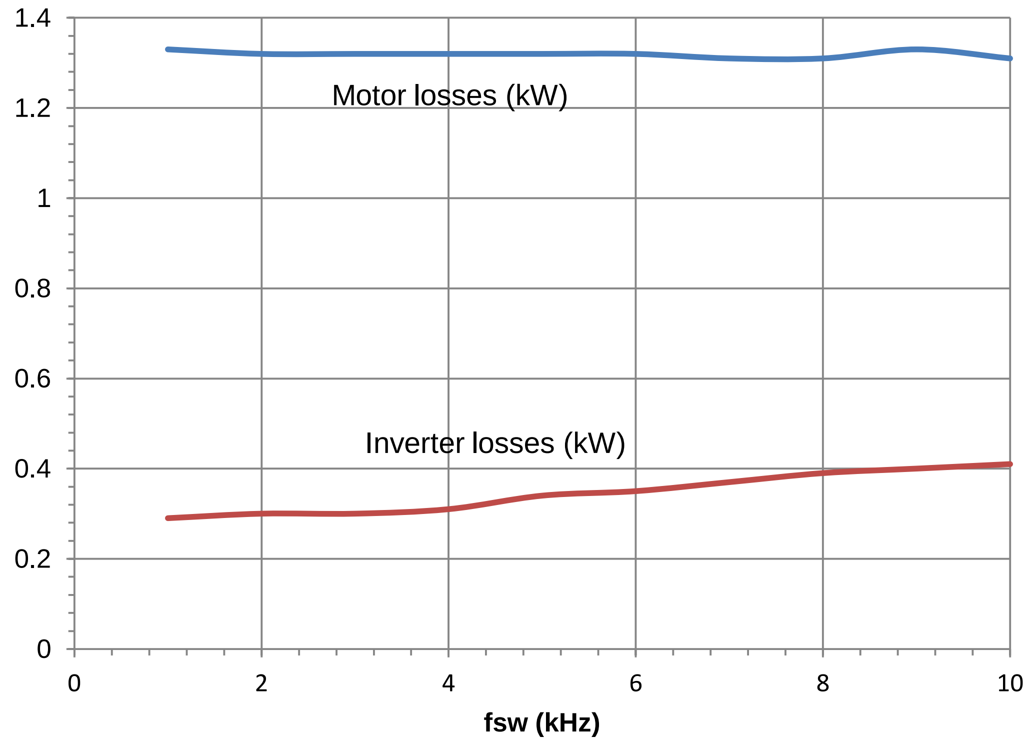
Effects of Switching Frequency for Motors

This study shows an increase in losses for the inverter with frequency and constant motor losses.

Induction motor

35 Hz fundamental frequency

70 Nm load

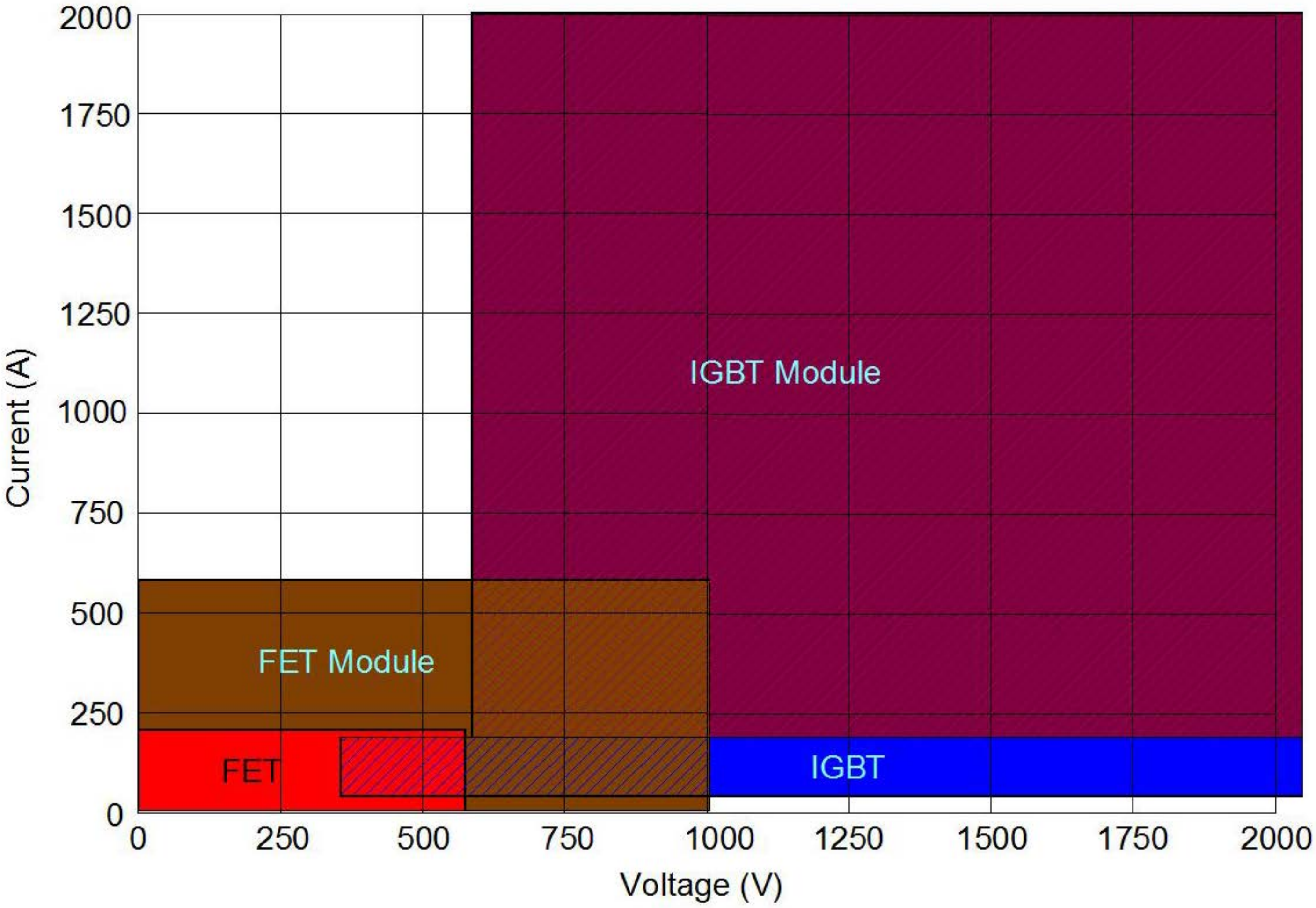


Source: Audible Noise and Losses in Variable Speed Induction Motor Drives with IGBT Inverters – Influency of Design and Switching Frequency, A. Malfait, R. Reekmans, R. Belmans, K. U. Leuven, Oct.6, 1994

Use of MOSFETs vs. IGBTs

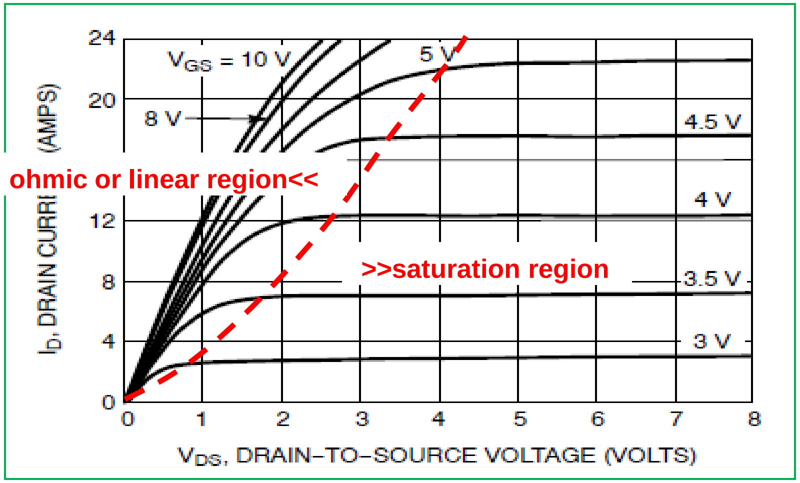
Frequency is generally the determining factor in the overlap areas.

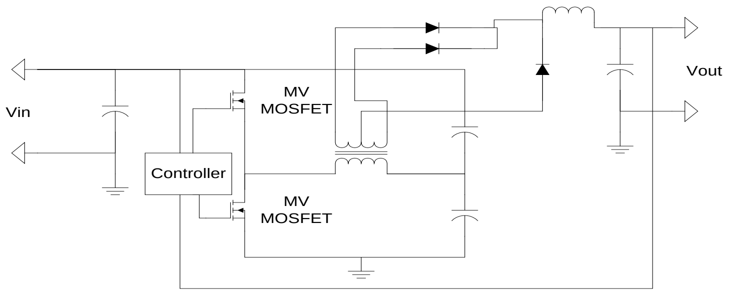
Voltage and current limits are based on device ratings and not system requirements.



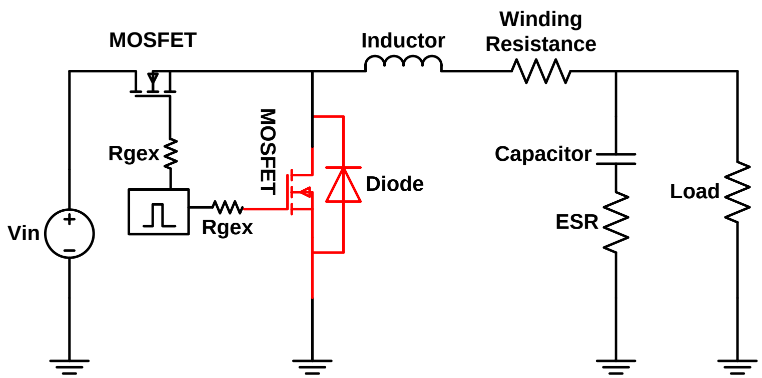
MOSFET Modes of Operation

Switch Mode

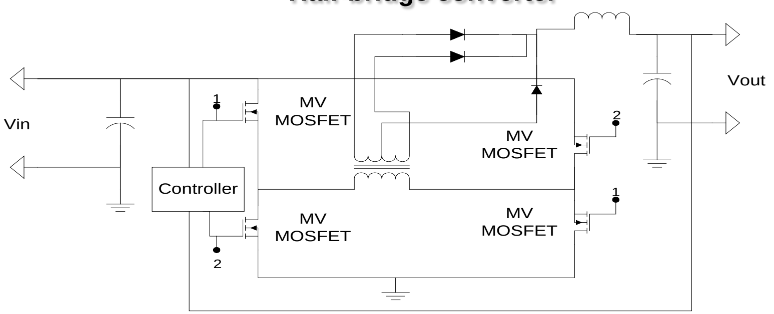




Half-bridge converter

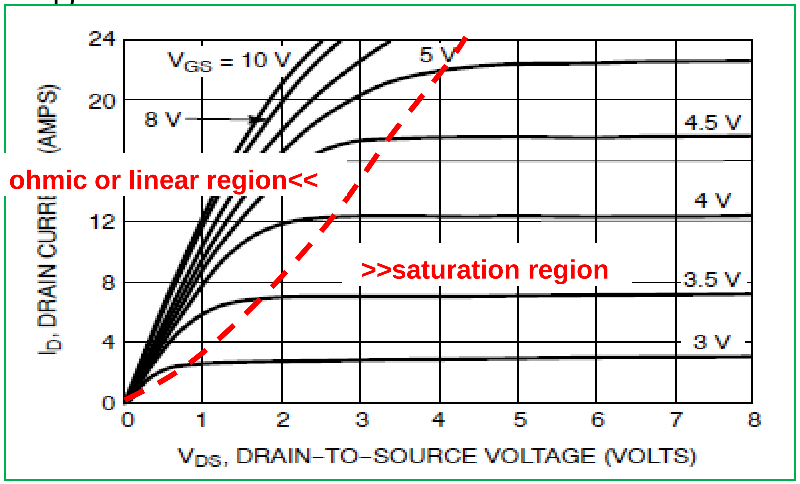


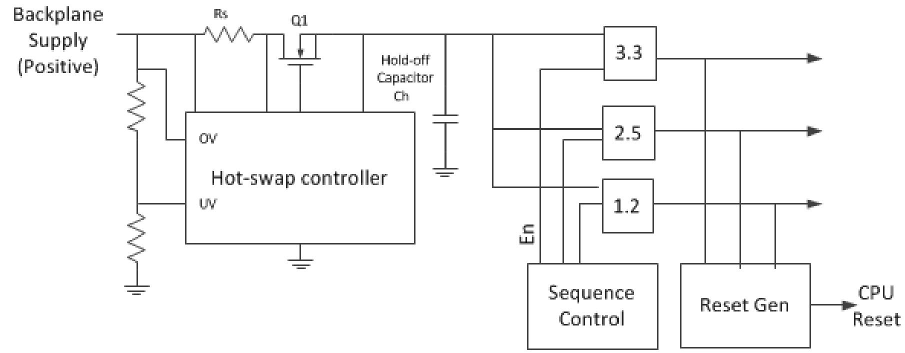
BUCK CONVERTER

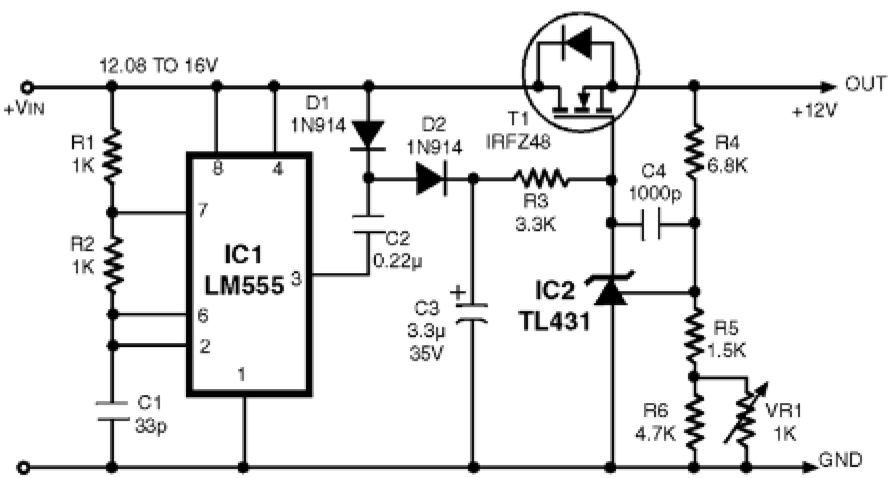


Full-bridge converter

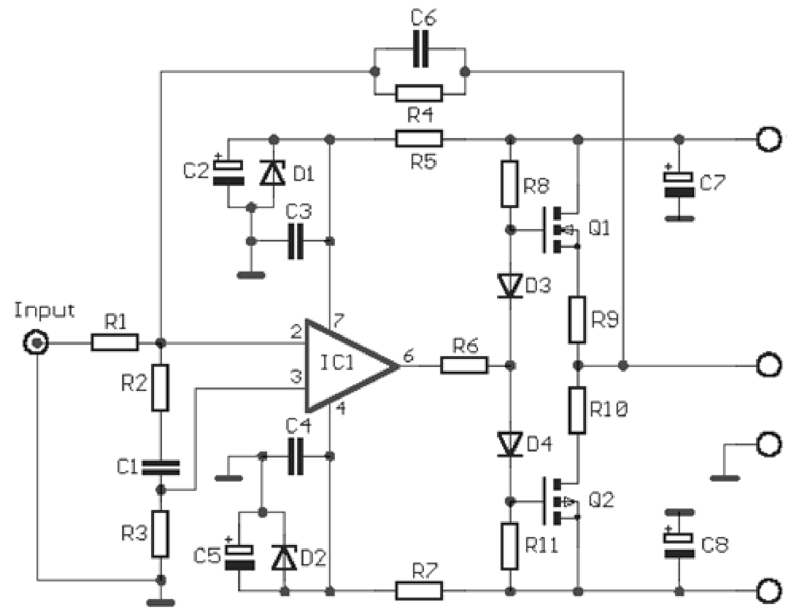
Saturation Mode





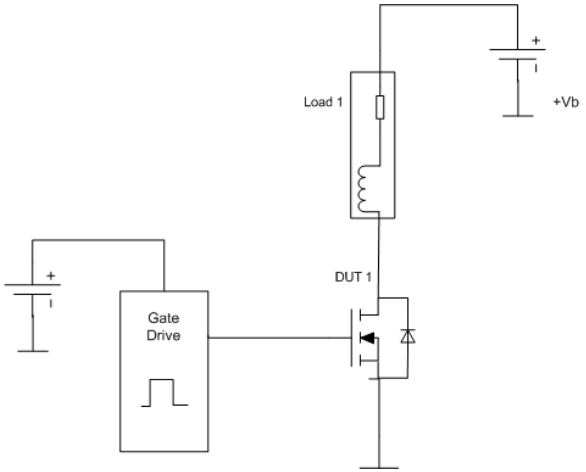


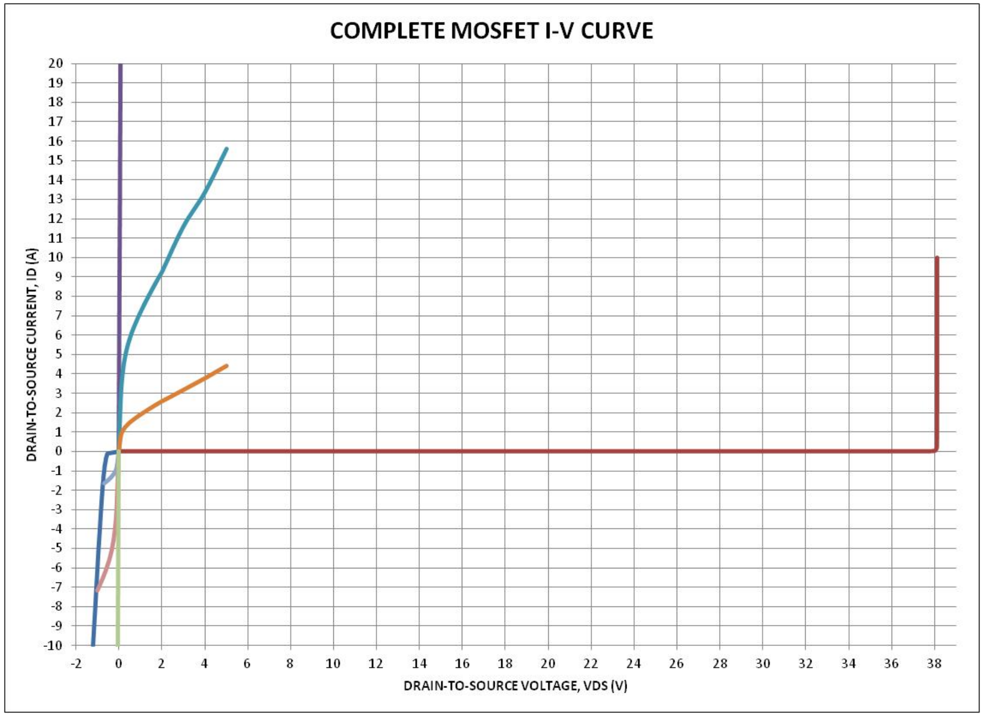
Linear Regulator



Audio Amplifier

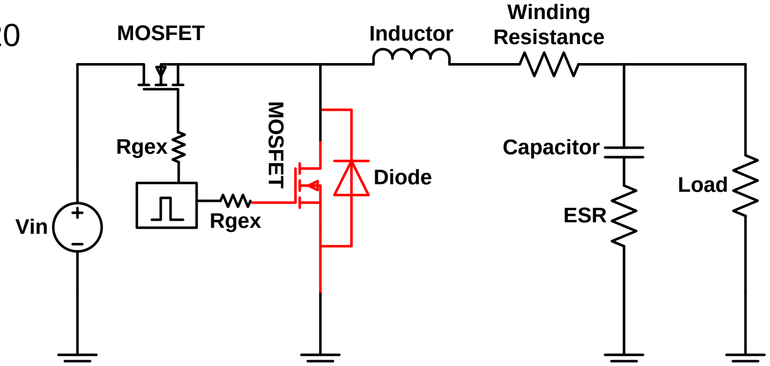
Unclamped Inductive Switching (UIS)

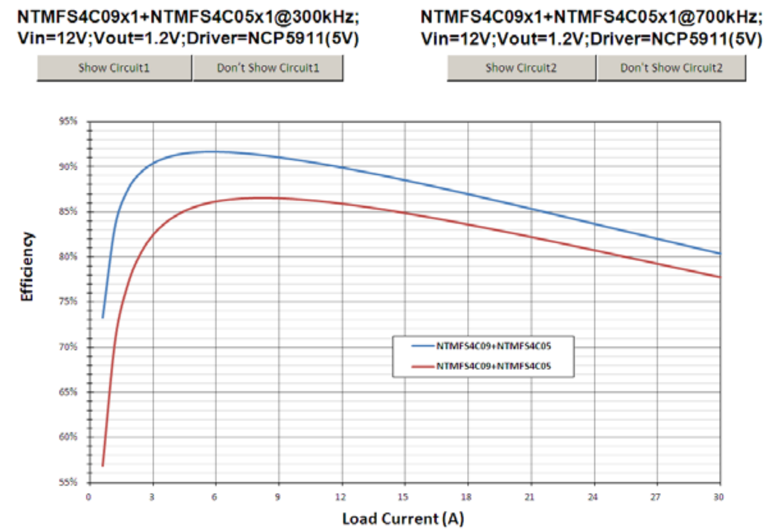




Switch Mode

Switch Mode Operation

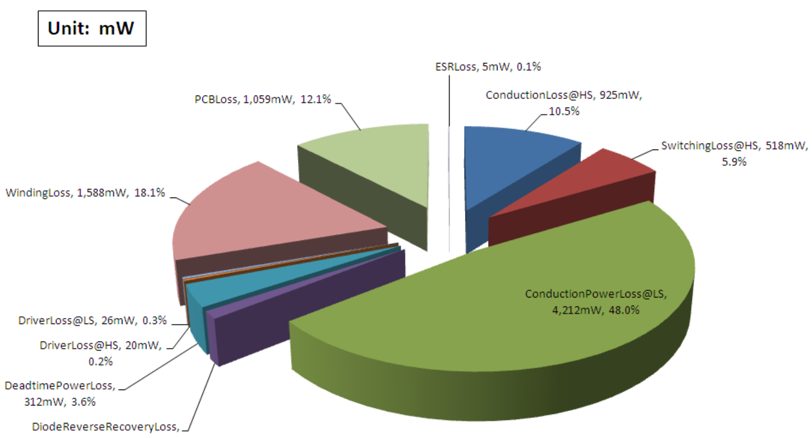




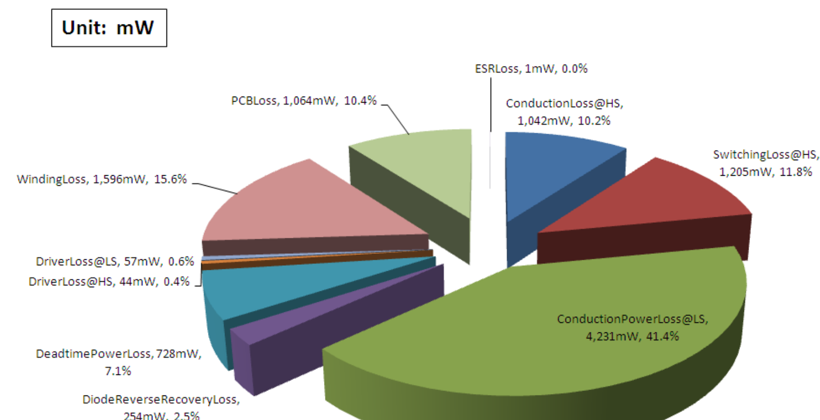
Power Loss:

- Conduction
- Switching
- Driver
- Diode Reverse recovery
- Dead time

Power Loss Components for Circuit 1 @ 30 A

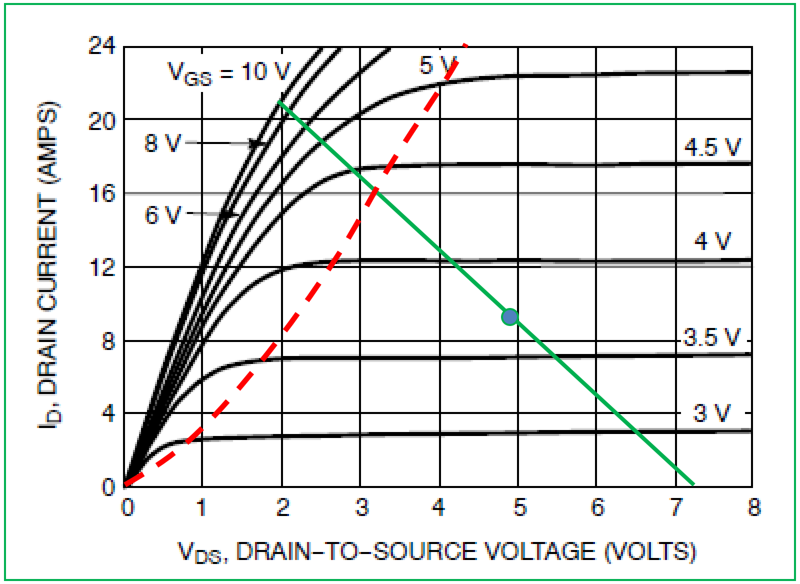


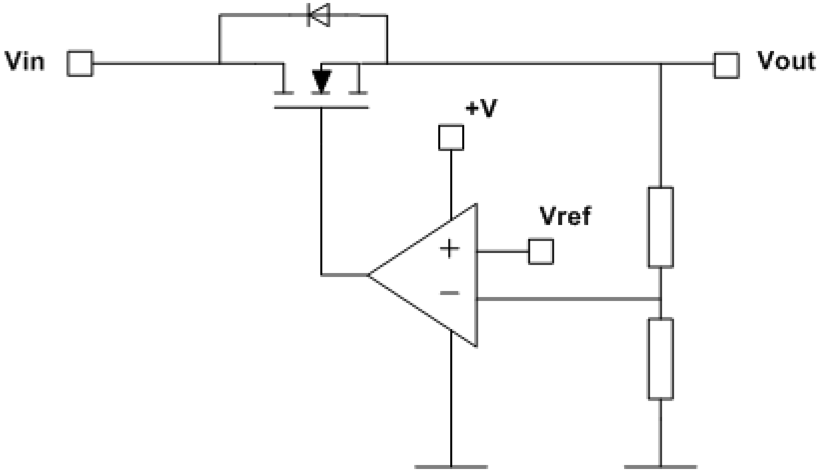
Power Loss Components for Circuit 2 @ 30 A



Saturation Mode

Saturation Operation





Saturation operation applications include:

- **linear regulators**
- **active clamp inductive load switches**
- **class A, B, AB amplifiers**

Saturation operation is also possible in fault modes such as:

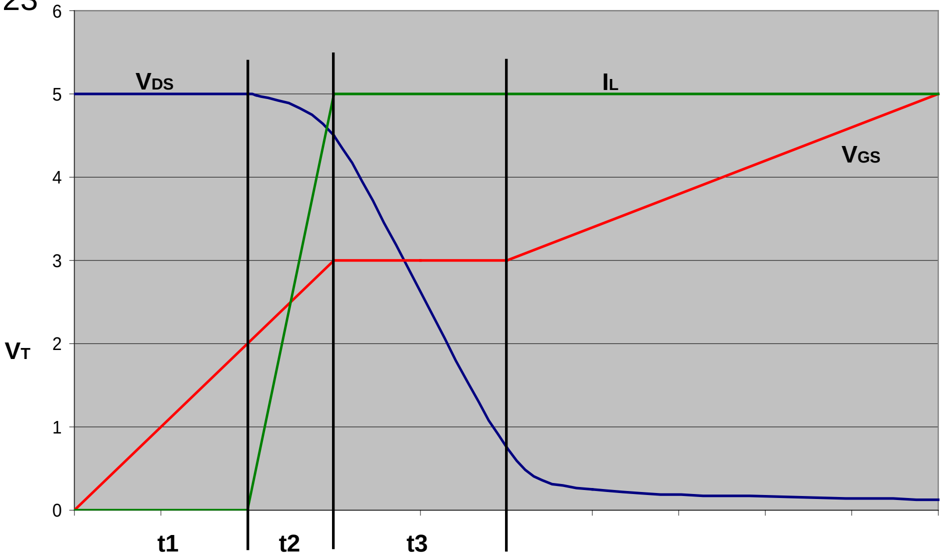
- **short circuit**

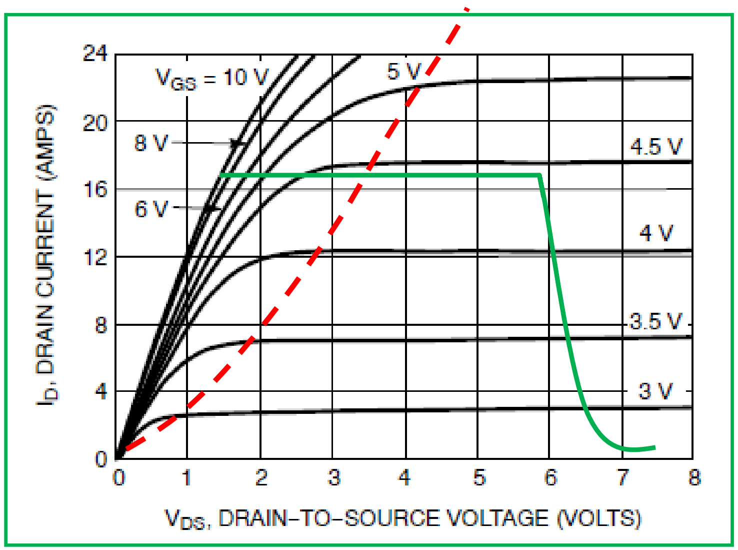
And other transient conditions such as:

- **in-rush current (filament switching, hot swap)**

However, note that for any switching cycle, the MOSFET must transit through the saturation region.

Saturation Operation



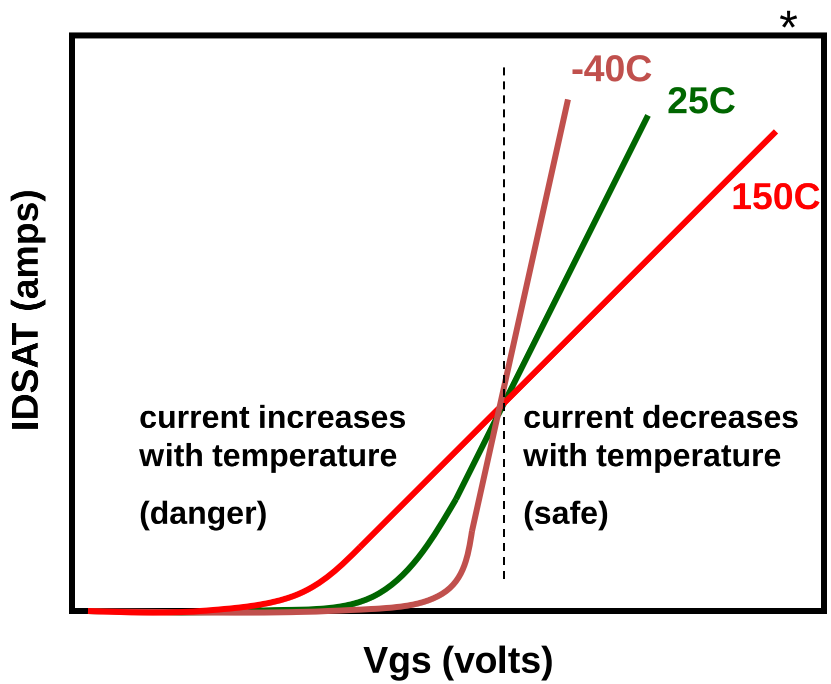


Normal switching of MOSFET transits thru saturation operation.

This is normally not an issue since transition time is on order of nano seconds to a few micro seconds.

However, some applications purposely slow down switching transitions to tens or even hundreds of microseconds. In these cases, issues associated with saturation operation must be considered.

Saturation Operation Issues



In addition to high power dissipation, saturation operation can also result in thermal instability, due to change in saturation current with junction temperature.

$$I_{D(sat)} \cong \frac{\mu_o \cdot C_{ox} \cdot W}{2 \cdot L}(V_{gs} - V_{th})^2$$

where,

$$\mu_o = f(T_J), \; \frac{\partial \mu_o}{\partial T_J} < 0 \qquad V_{th} = f(T_J), \; \frac{\partial V_{gs}}{\partial T_J} < 0$$

At high V_{gs}, the μ_o term dominates and $I_{D(sat)}$ decreases. At low V_{gs}, the delta V_{gs} term dominates and $I_{D(sat)}$ increases with junction temperature.

When $I_{D(sat)}$ has a positive temperature coefficient , the possibility exists for thermal runaway, where:

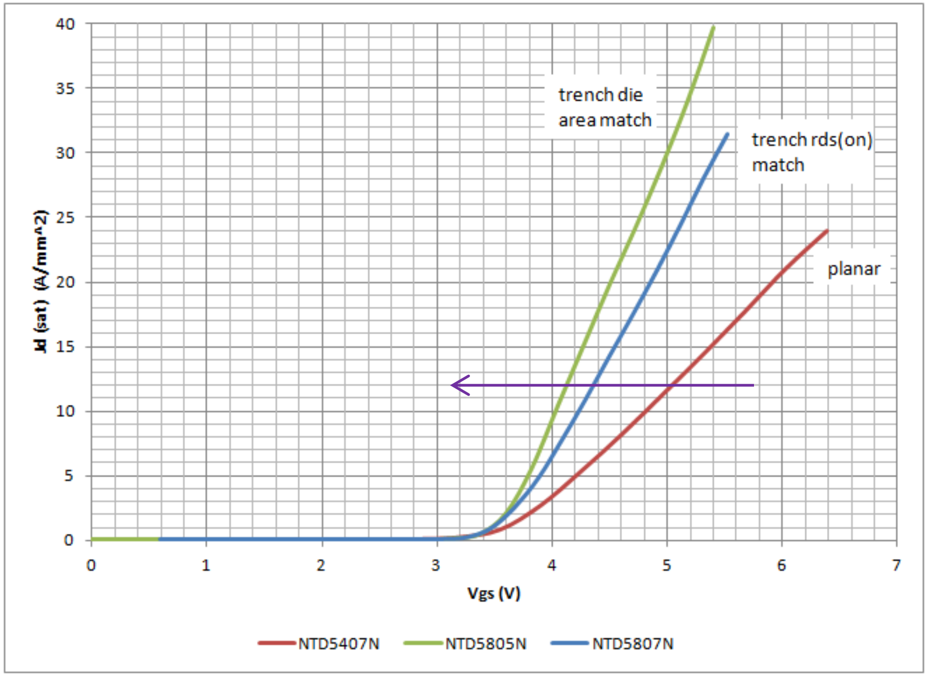
$$\frac{\partial P_{gen}}{\partial T_J} \geq \frac{\partial P_{dis}}{\partial T_J}$$

Which can be written as:

$$V_D \cdot \frac{\partial I_{D(sat)}}{\partial T_J} \geq \frac{1}{r(t)}$$

* *Special thanks to S. Robb for plot*

Saturation Operation Issues: Technology



Device	Tech	Active Area (mm2)	Typ. Rds(on) Vgs = 10 V, (mΩ)
NTD5407N	40V HD3e	2.66	21
NTD5807N	40V T2	1.46	20
NTD5805N	40V T2	2.71	7.6

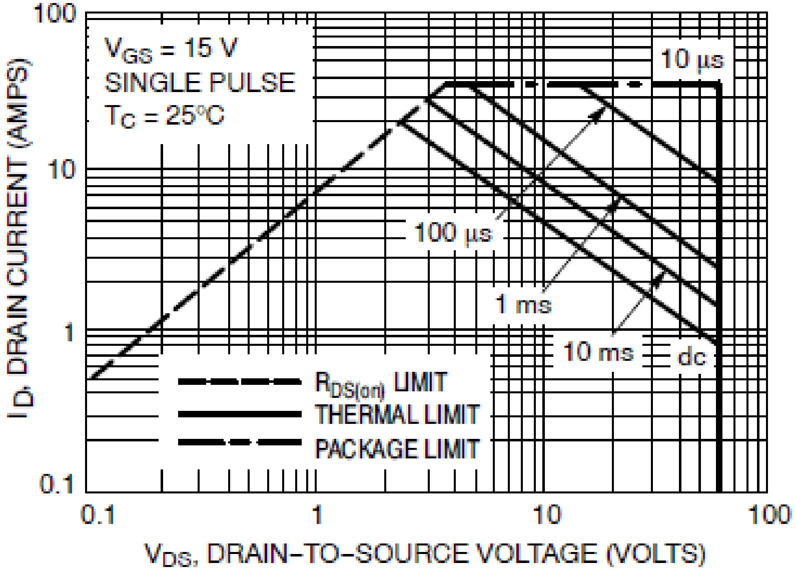
Compared to planar, trench technology affords much higher channel density (W/area). Thus at a given current density, the trench device will operate closer to V_{th}.

$$J_{D(sat)} \cong \frac{\mu_o \cdot C_{ox} \cdot W}{2 \cdot L \cdot Area}(V_{gs} - V_{th})^2$$

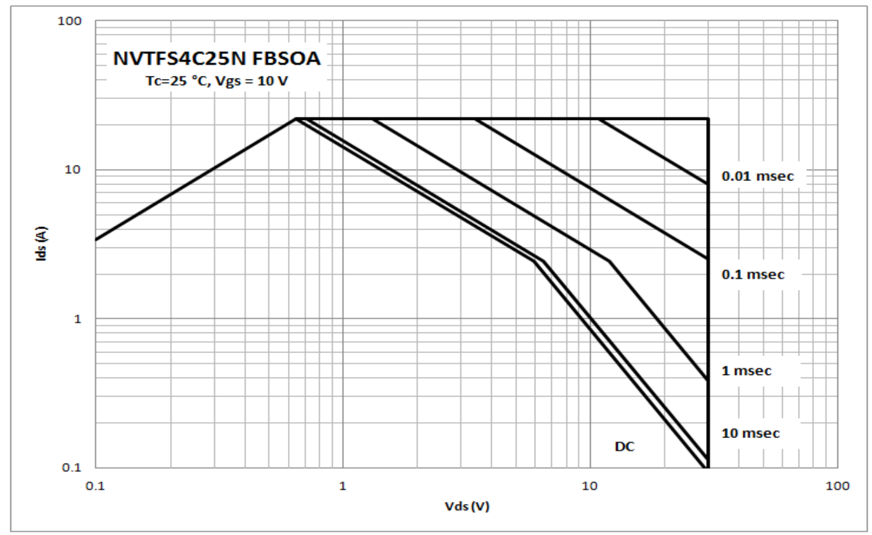
Operation near V_{th} increases the probability of thermal instability, thus trench technology devices are more likely to suffer thermal runaway during saturation operation.

Safe Operating Area

Traditional FBSOA



Corrected FBSOA



Key points:
- **Traditional assumed constant power which was okay for planar technology**
- **Newer Trench Technologies require an adjustment to account for higher gain (GFS)**

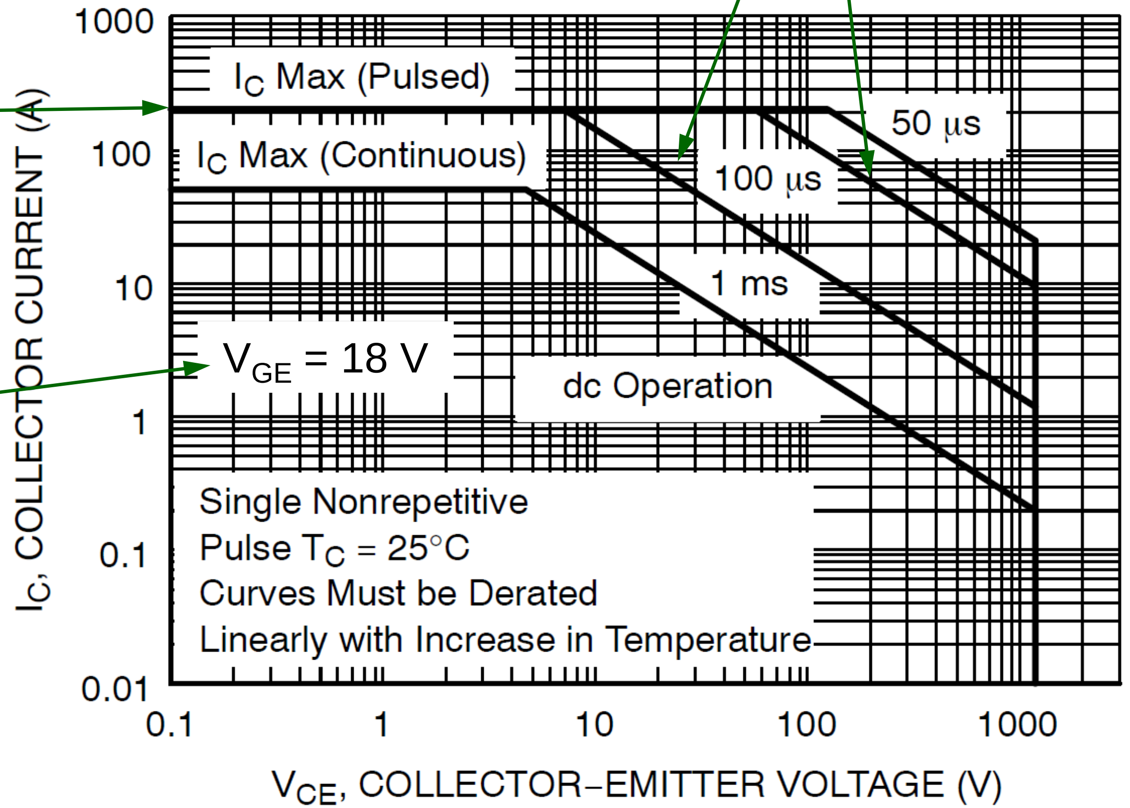
FBSOA (IGBTs)

Forward biased –
Device is conducting

Pulsed curves are for a single pulse with the package at 25 °C

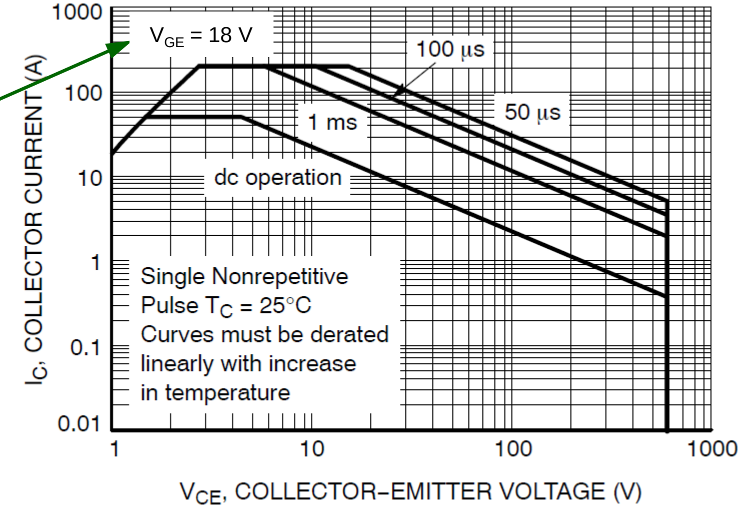
Exceeding the I_CMax rating can lead to burnout or latchup

DC curves are valid as long as $T_J \leq 150$ °C & $V_{GE} \approx 18$ V

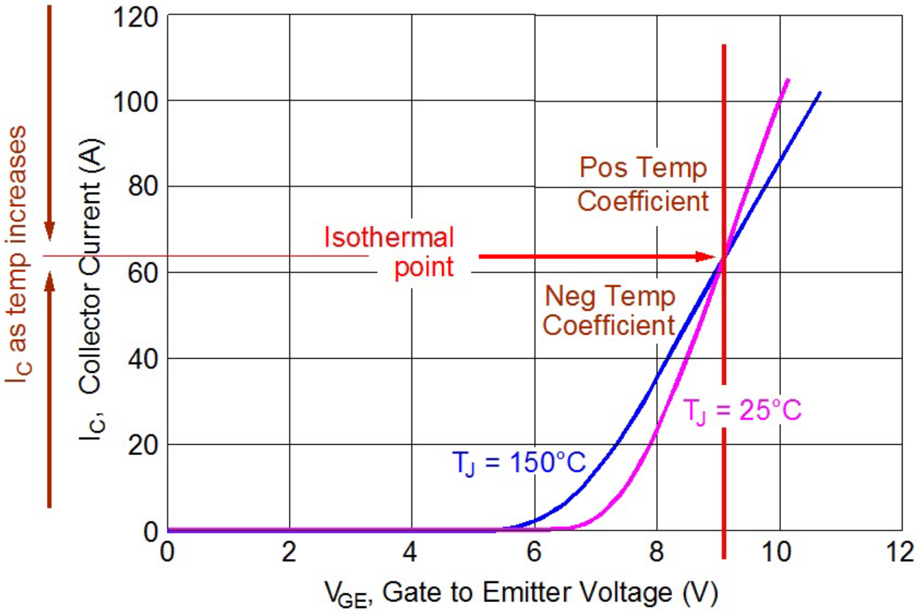


FBSOA (FETs & IGBTs)

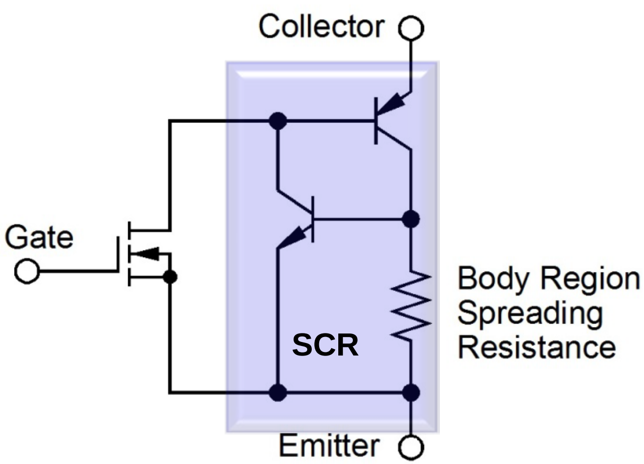
The SOA curves are based on the assumption that there is a uniform current distribution across the die. i.e. no hot spots. A high V_{GE} is required.

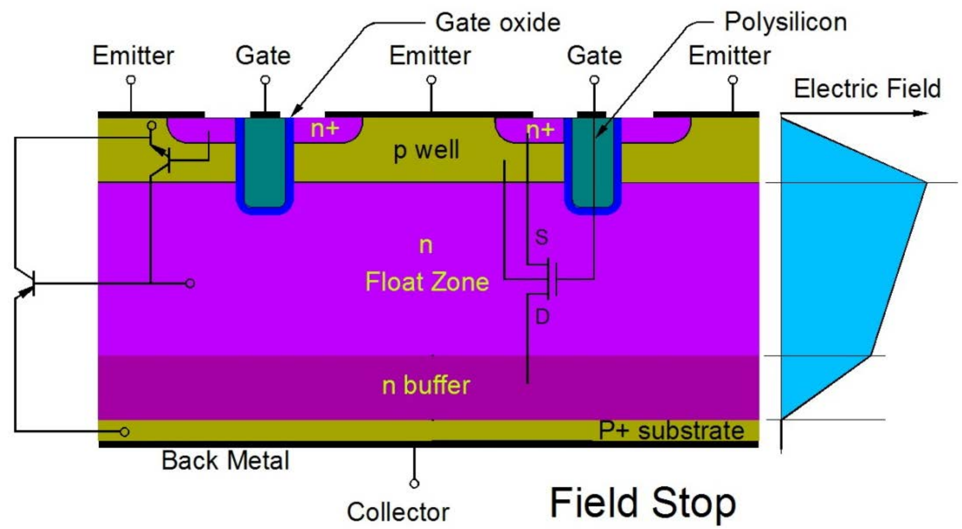


If the IGBT is biased in the negative temp coefficient area, the resistivity of the cells will decrease with temperature and hot spots will develop.



The gain of the npn and pnp transistors increases with temperature which lowers the current at which the parasitic SCR will latch. Latchup is more easily achieved at high temperatures

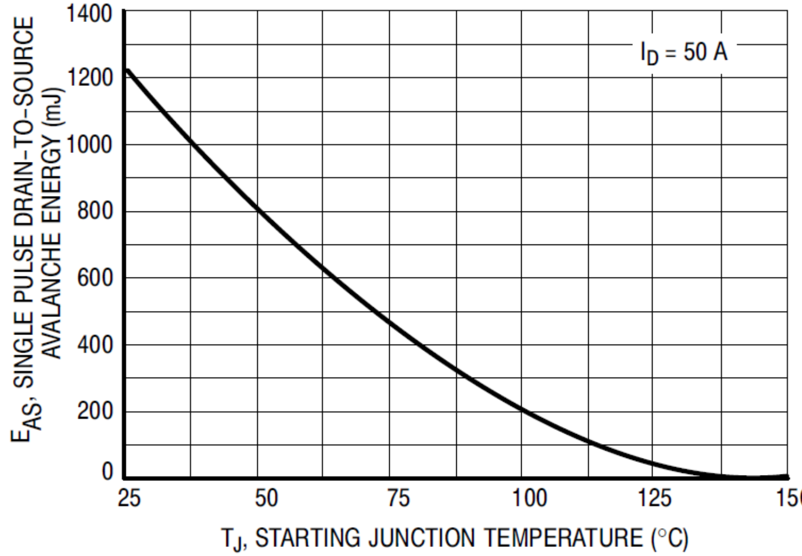


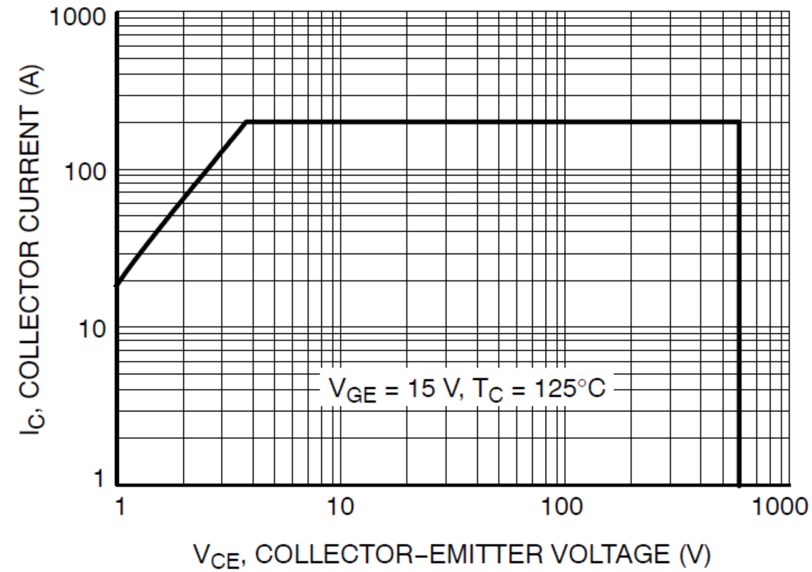


RBSOA (FETs & IGBTs)

Reverse biased –
Gate is low

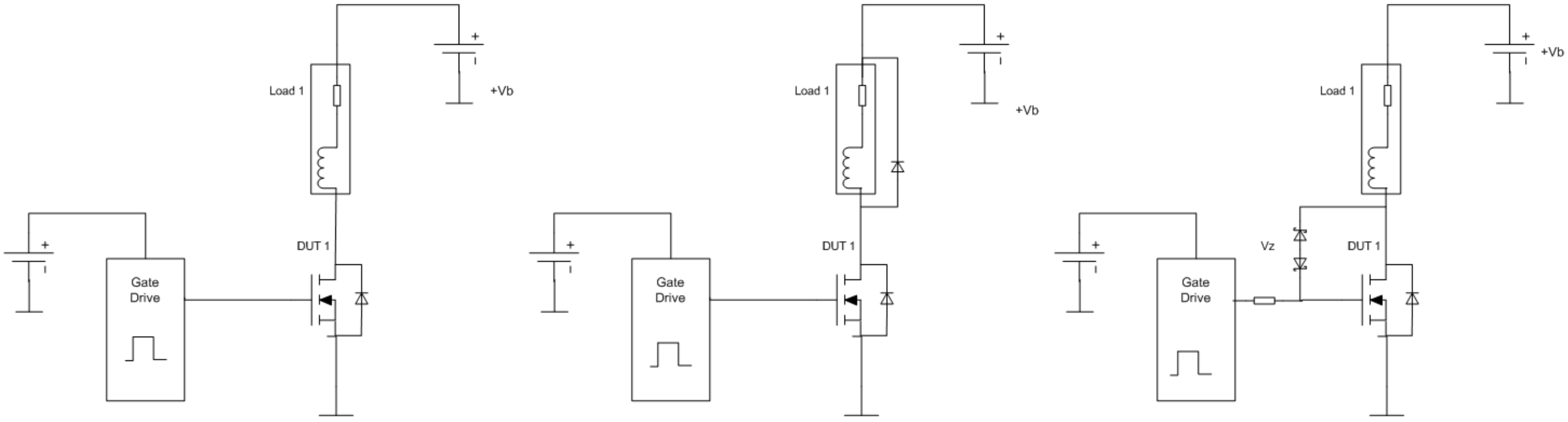
The RBSOA is a measure of the avalanche capability of the device – which is also the UIS rating. It can be displayed in several ways.





UIS (Unclamped Inductive Spike)

Low-side Inductive Switching



Unclamped (UIS)

At switch off*:

$$V_{DS} = V_{AV} \cong 1.3 \cdot BV_{DSS}$$

Clamped (re-circ)

At switch off*:

$$V_{DS} = V_b + V_{diode} < V_{AV}$$

Active Clamp

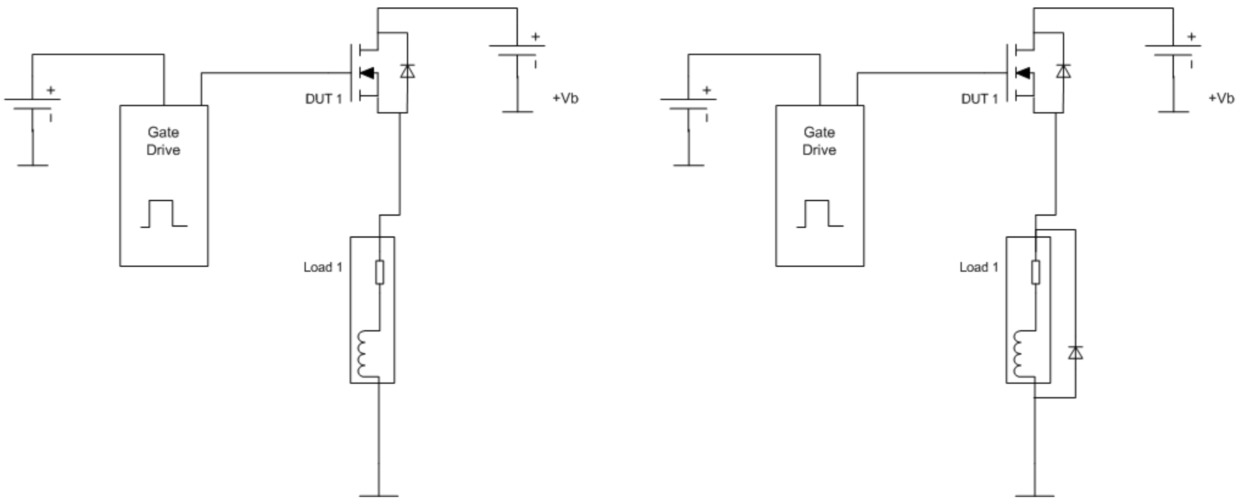
At switch off*:

$$V_{DS} \cong V_Z + V_{th} < V_{AV}$$

UIS data applies only to scenarios where FET drain to source junction avalanches

*** $V_{g\ gate\ drive} = 0$ V**

High-side Inductive Switching



Unclamped (self-active clamp)

At switch off*:

$$V_{DS} \cong V_b + V_{th} < V_{AV}$$

Clamped (re-circ)

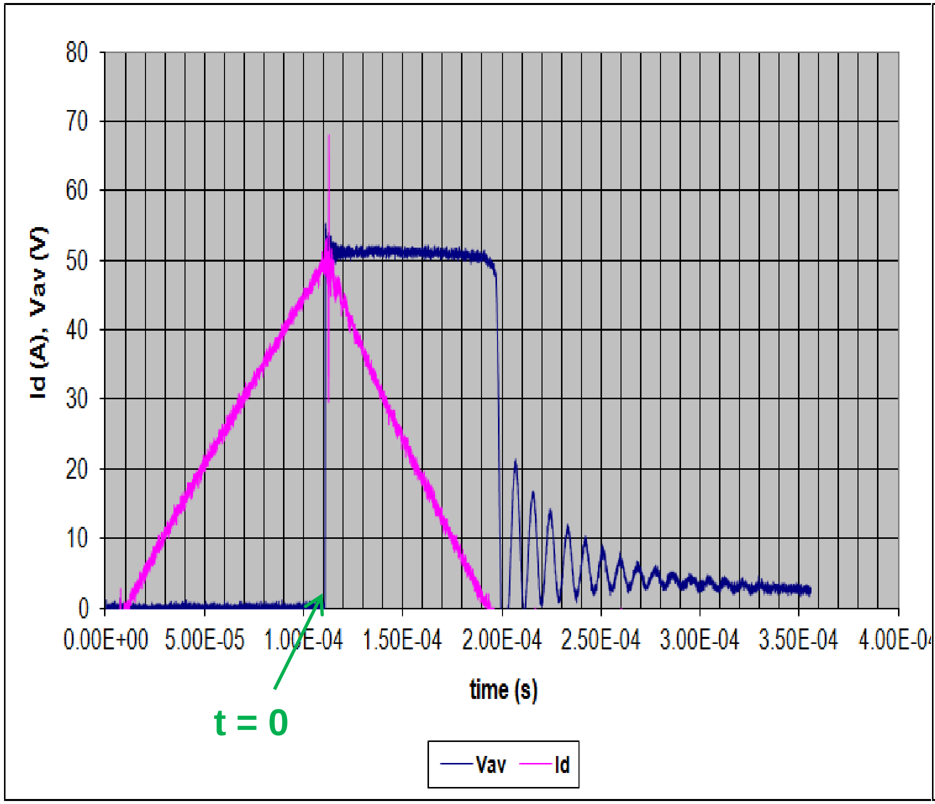
At switch off*:

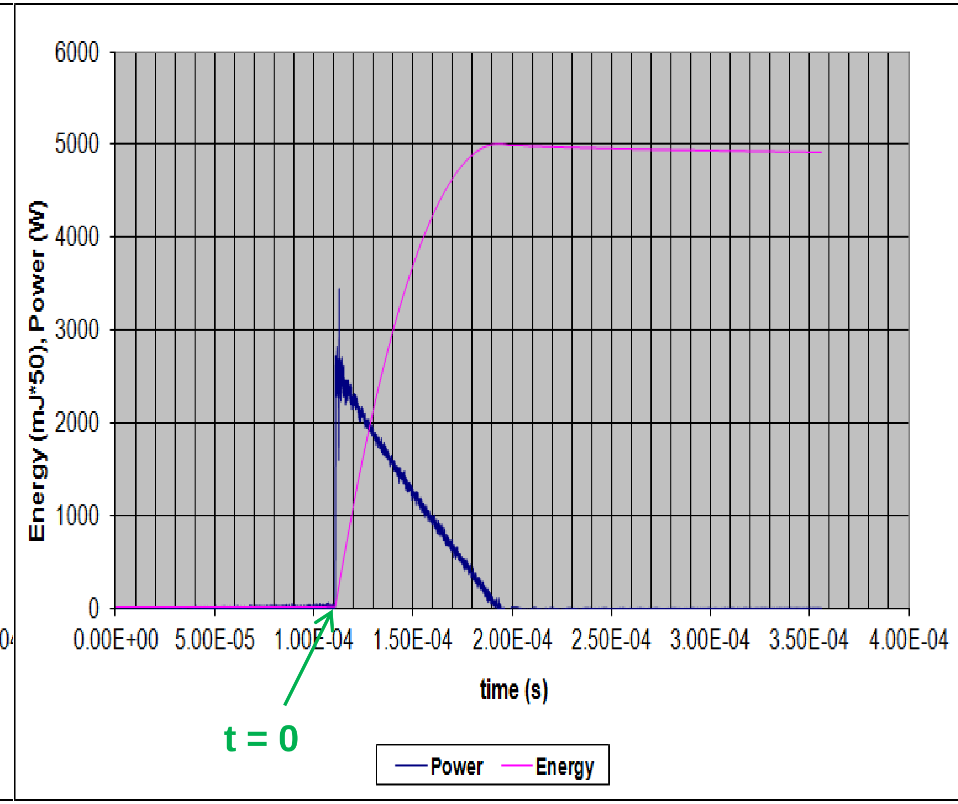
$$V_{DS} = V_b + V_{diode} < V_{AV}$$

FET in high-side switching configuration generally does not avalanche

* $V_{g\text{ to gnd}} = 0$ V

UIS Waveforms

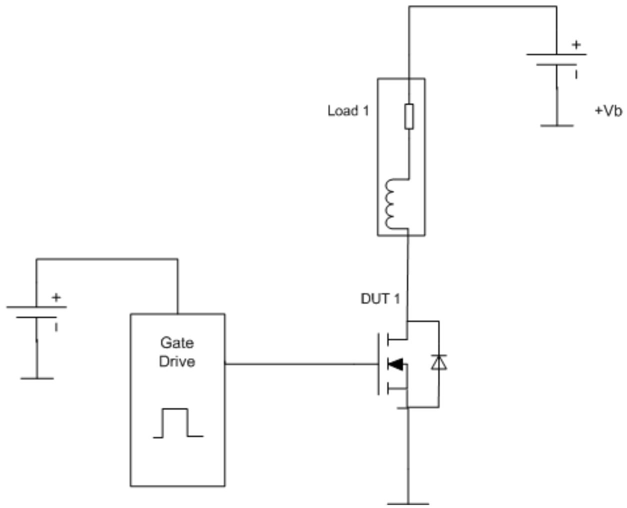


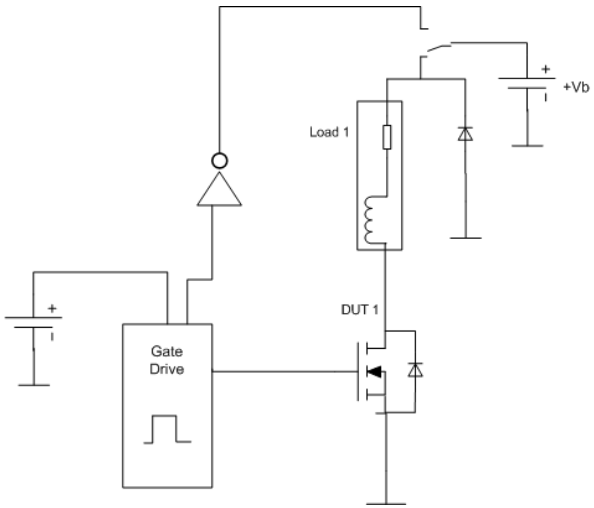


General form for FET energy during avalanche

$$E = \int_0^{t_{AV}} P \cdot dt = V_{AV} \cdot \int_0^{t_{AV}} i(t) \cdot dt$$

UIS Equations





Vb supply in circuit at switch-off*:

$$E = \frac{1}{2} \cdot L \cdot I_{PK}{}^{2} \cdot \frac{V_{AV}}{(V_{AV} - V_b)}$$

$$t_{AV} = \frac{L \cdot I_{PK}}{(V_{AV} - V_B)}$$

$$P_{ave} = \frac{I_{PK} \cdot V_{AV}}{2}$$

Vb supply removed at switch-off*:

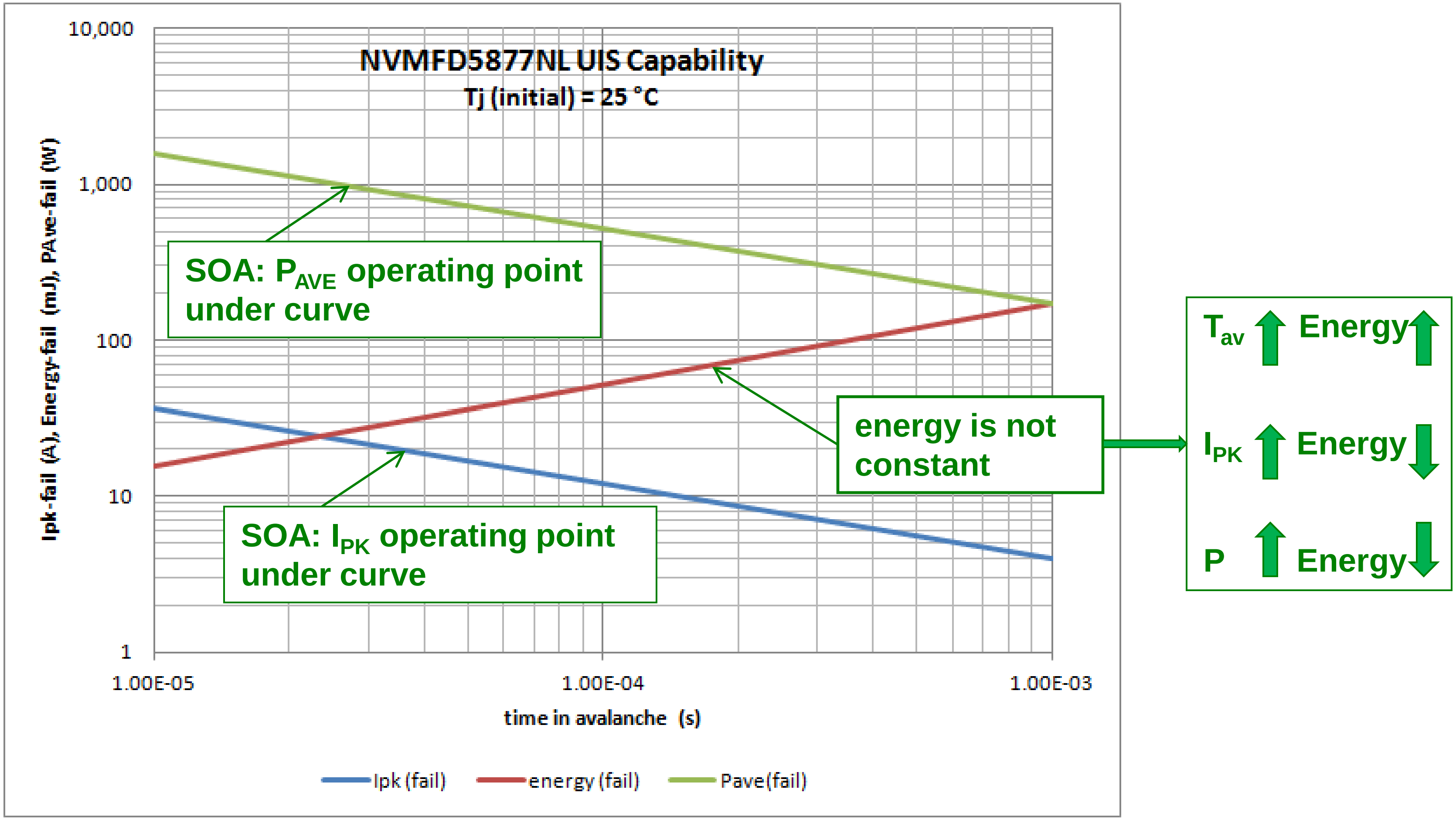
$$E = \frac{1}{2} \cdot L \cdot I_{PK}{}^{2}$$

$$t_{AV} = \frac{L \cdot I_{PK}}{V_{AV}}$$

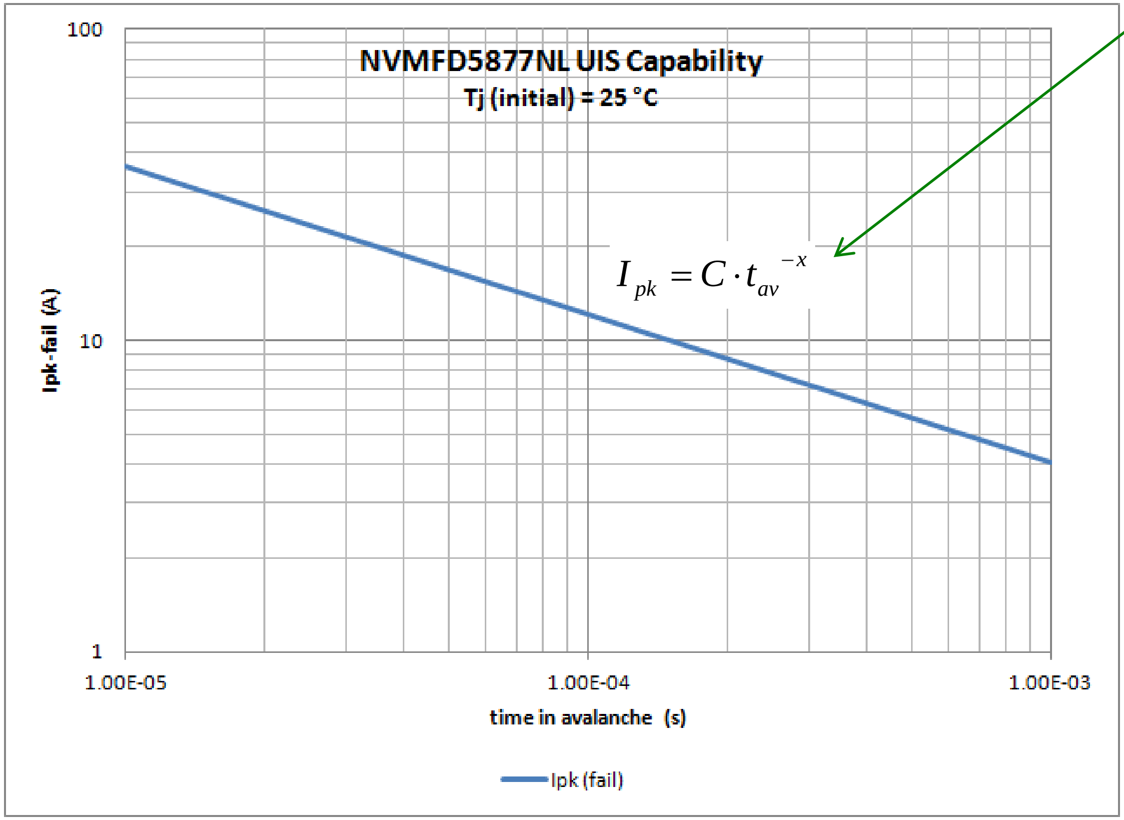
$$P_{ave} = \frac{I_{PK} \cdot V_{AV}}{2}$$

*** Series R in circuit zero or negligible**

Quantifying UIS Power MOSFET UIS Capability



Quantifying UIS Power MOSFET UIS Capability



I_{PK} as a f(t_{AV}) follows a power function.

Re-arranged this function is of the form:

$$K = I_{pk}^{1/x} \cdot t_{av}$$

where,

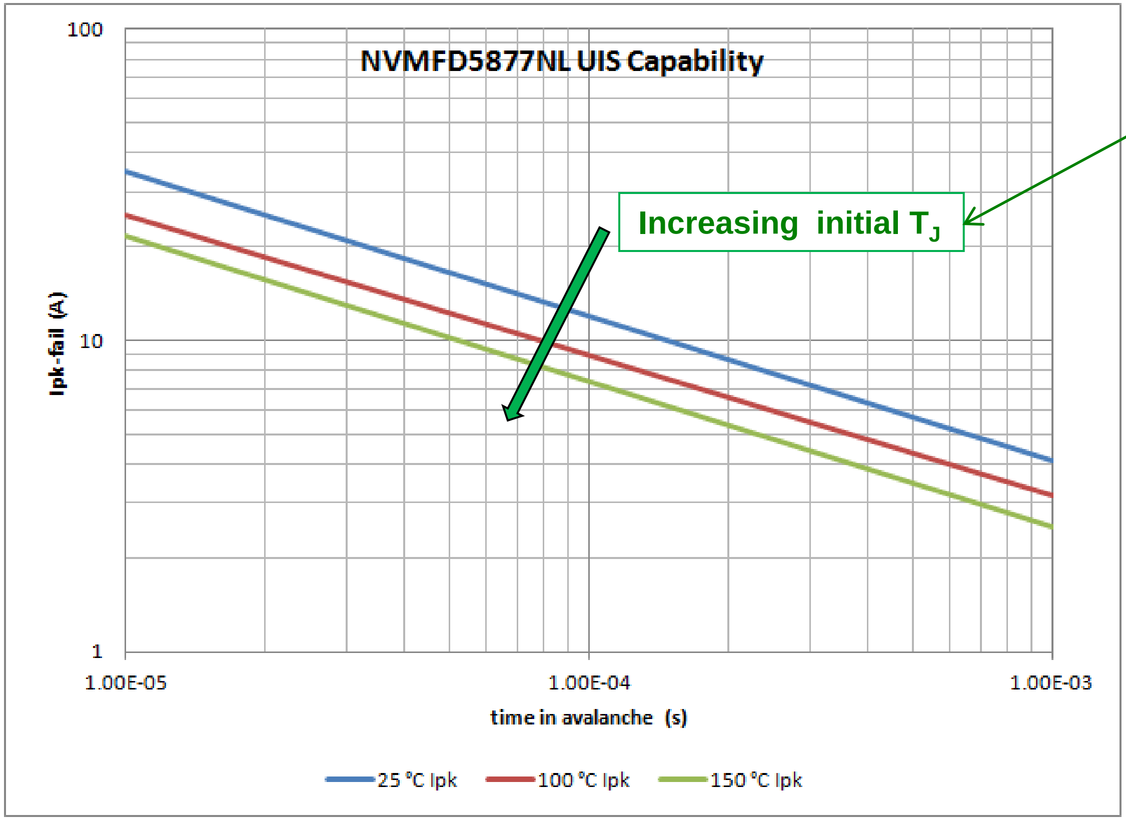
$$K = C^{1/x}$$

Typically the term 1/x ~ 2, thus typical FET UIS capability follows the relationship:

$$I_{pk}^{\approx 2} \cdot t_{av} = K$$

I^2t = constant indicates a thermal based failure mode; e.g. fuses (that melt open) follow the same relationship.

Quantifying UIS Power MOSFET UIS Capability



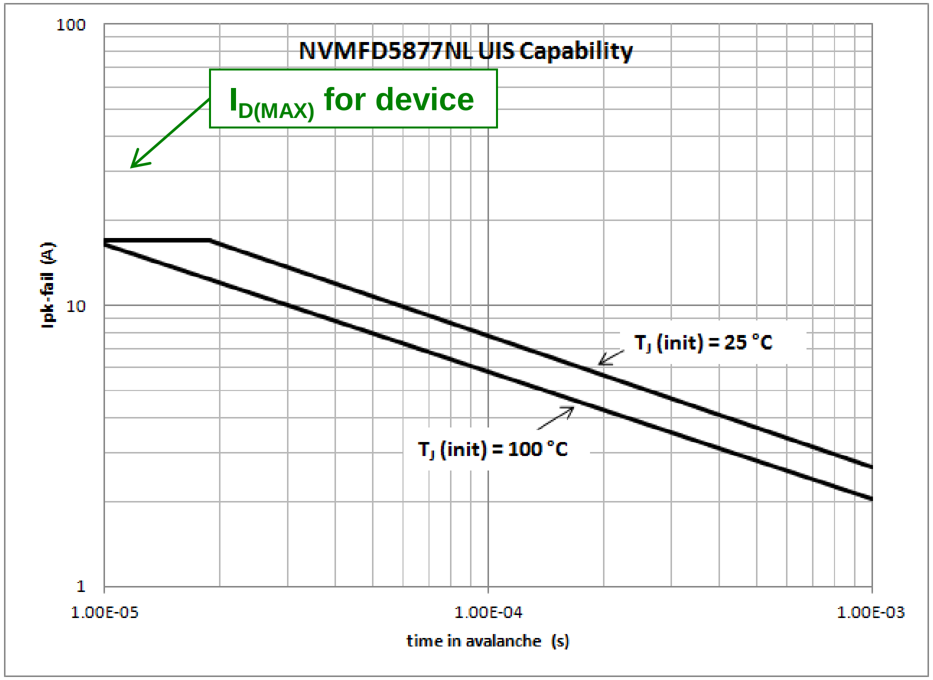
As the initial junction temperature increases device UIS capability decreases.

Thermal device failures occurs when device junction temperature reaches $T_{intrinsic}$. Thus as the initial junction temperature increases there is less thermal headroom (ΔT_J to failure).

Less thermal headroom means less power capability and thus less energy required to reach intrinsic junction temperature.

Specifying UIS on Data Sheet

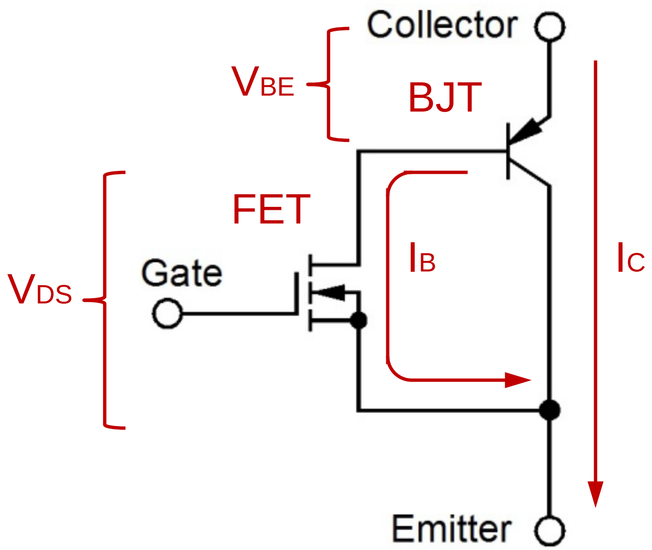
Single Pulse Drain–to–Source Avalanche Energy (T_J = 25°C, V_{DD} = 24 V, V_{GS} = 10 V, R_G = 25 Ω)	($I_{L(pk)}$ = 14.5 A, L = 0.1 mH)	E_{AS}	10.5	mJ
	($I_{L(pk)}$ = 6.3 A, L = 2 mH)		40	



- **Another way to display UIS capability SOA is to plot I_{PK} as a function of t_{AV} for different starting junction temperatures.**
- **With knowledge of the device avalanche voltage (V_{AV}), the user can determine the application operating point on the plot and determine if operation is within the SOA.**

Short Circuit Ratings

IGBT Short Circuit Ratings



Adjusting the transconductance of the FET will affect the base drive of the BJT, which will affect the overall power dissipation during a short.

This will also affect the Vce(sat) of the IGBT.

Application	Short circuit rating
Motor Drives	10 µs for most equipment 5 µs for some newer equipment
White Goods	5 µs
UPS	0 – 5 µs
Solar	10 µs
PFC	10 µs

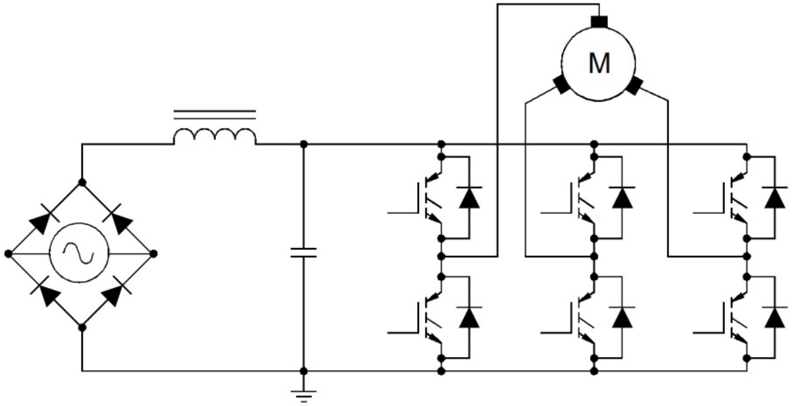
Inverter Topologies

Inverter Topologies – H-bridge

Solar Inverter

Motor Drive

- **Motor Drives**
- **UPS**
- **Solar Inverters**



3 phase H-bridge

- Well understood topology
- Good at high power levels
- Existing code for many microcontrollers
- Power switches rated for full input voltage
- All switches operate at the switching frequency

1200 V, Inverter IGBTs

Part Number	Release	$V_{CE(sat)}$	Trr	Current	Short Ckt	Package	Tech
NGTB40N120FLWG	Released	1.75	250	40	10	TO-247	FSI
NGTB15N120FLWG	Released	1.90	100	15	10	TO-247	FSI
NGTB25N120FLWG	Released	1.70	200	25	10	TO-247	FSI
NGTB40N120FL2WG	Q2, '13	2.00	200	40	10	TO-247	FSII
NGTB25N120FL2WG	Q2, '13	2.00	200	25	10	TO-247	FSII
NGTB15N120FL2WG	Q3, '13	2.00	200	15	10	TO-247	FSII
NGTB40N120L2WG	Q3, '13	1.70	400	40	10	TO-247	FSII
NGTB25N120L2WG	Q3, '13	1.70	400	25	10	TO-247	FSII
NGTB25N120L2WG	Q3, '13	1.70	400	15	10	TO-247	FSII

600 V, Inverter IGBTs

Part Number	Release	$V_{CE(sat)}$	Trr	Current	Short Ckt	Package	Tech
NGTB30N60FWG	Production	1.50	189	30	5	TO-247	NPT
NGTB50N60FWG	Production	1.40	180	50	5	TO-247	NPT
NGTB30N60FLWG	Production	1.50	100	30	5	TO-247	FS1
NGTB50N60FLWG	Production	1.50	100	50	5	TO-247	FS1
NGTB75N60FL2WG	Q3, '13	1.85	80	75	5	TO-247	FSII
NGTB50N60FL2WG	Q4, '13	1.85	80	50	5	TO-247	FSII
NGTB40N60FL2WG	Q4, '13	1.85	80	40	5	TO-247	FSII
NGTB30N60FL2WG	Q4, '13	1.85	80	30	5	TO-247	FSII
NGTB75N60L2WG	Q4, '13	1.50	150	75	5	TO-247	FSII
NGTB50N60L2WG	Q4, '13	1.50	150	50	5	TO-247	FSII
NGTB40N60L2WG	Q4, '13	1.50	150	40	5	TO-247	FSII
NGTB30N60L2WG	Q4, '13	1.50	150	30	5	TO-247	FSII

1200 V, Motor Drive IGBTs

Part Number	Release	$V_{CE(sat)}$	Trr	Current	Short Ckt	Package	Tech
NGTB15N120LWG	Production	1.80	300	15	5	TO-247	FSI
NGTB20N120LWG	Production	1.80	300	20	5	TO-247	FSI
NGTB25N120LWG	Production	1.85	300	25	5	TO-247	FSI
NGTB30N120LWG	Production	1.80	420	30	5	TO-247	FSI
NGTB40N120LWG	Production	1.90	420	40	5	TO-247	FSI

600 V, Motor Drive IGBTs

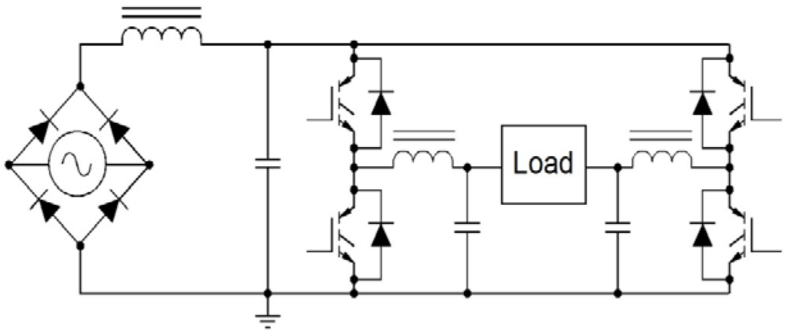
Part Number	Release	$V_{CE(sat)}$	Trr	Current	Short Ckt	Package	Tech
NGTB15N60EG	Production	1.70	270	15	10	TO-220	NPT
NGTB15N60S1EG	Production	1.50	270	15	5	TO-220	NPT
NGTG15N60S1EG	Production	1.50	270	15	5	TO-220	NPT

Inverter Topologies – H-bridge

HF Welder

UPS

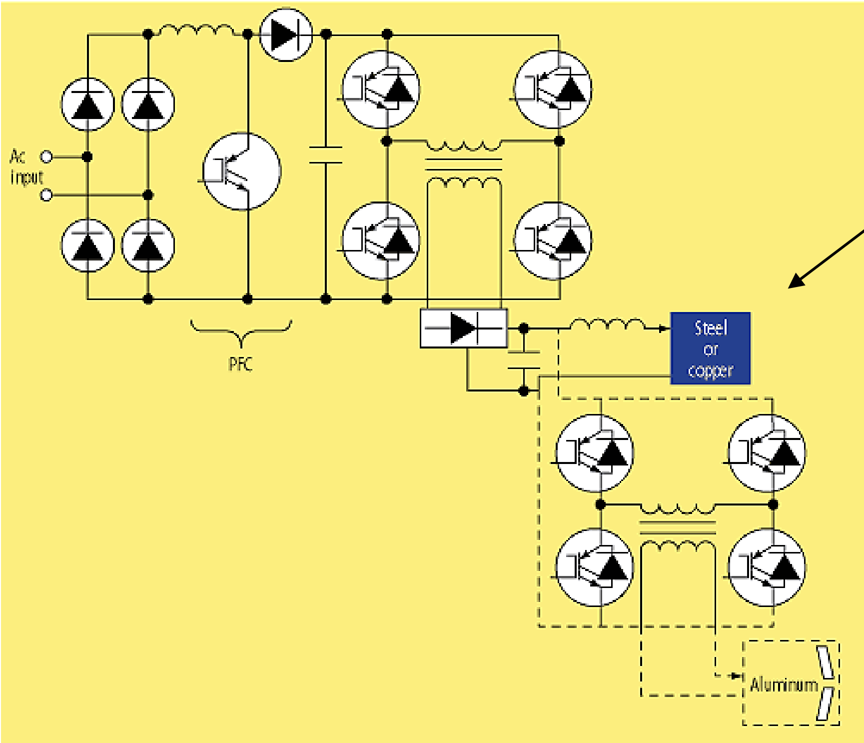
- **High Frequency Welders**
- **UPS**
- **Solar Inverters**



Single phase H-bridge

- Well understood topology
- Good at medium power levels
- Existing code for many microcontrollers
- Power switches rated for full input voltage
- Two switches operate at the switching frequency and *two at fundamental frequency*

Inverter Topologies - Welding



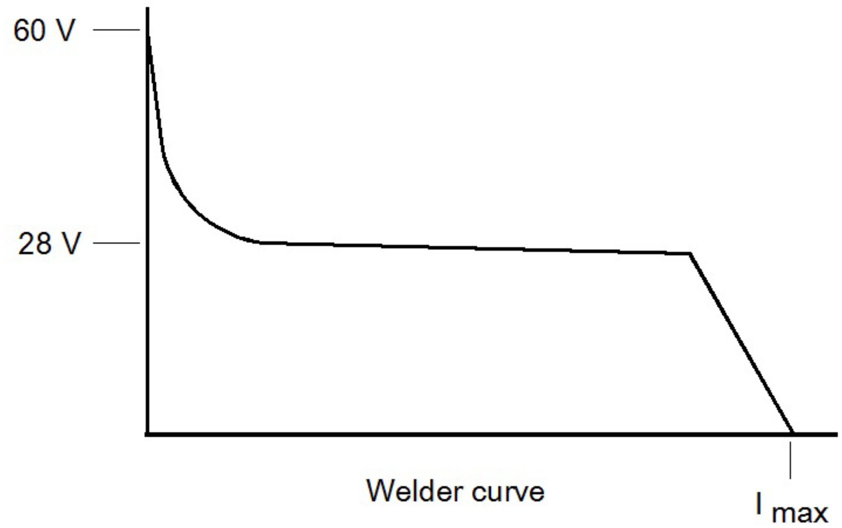
PWM rectified DC output
(low voltage/high current)

Some metals require a square wave output

- Switching Frequencies up to 100 KHz
- Increase in frequency reduces size of magnetics
  - Lighter – more portable
  - Complex output circuit controls for better performance

Voltage	Current	Packages
600/1200V	40A	TO-220, TO-220FP
Frequency	60KHz	
Application	Co-packaged rectifier, soft-switching	

Inverter Topologies - Welding



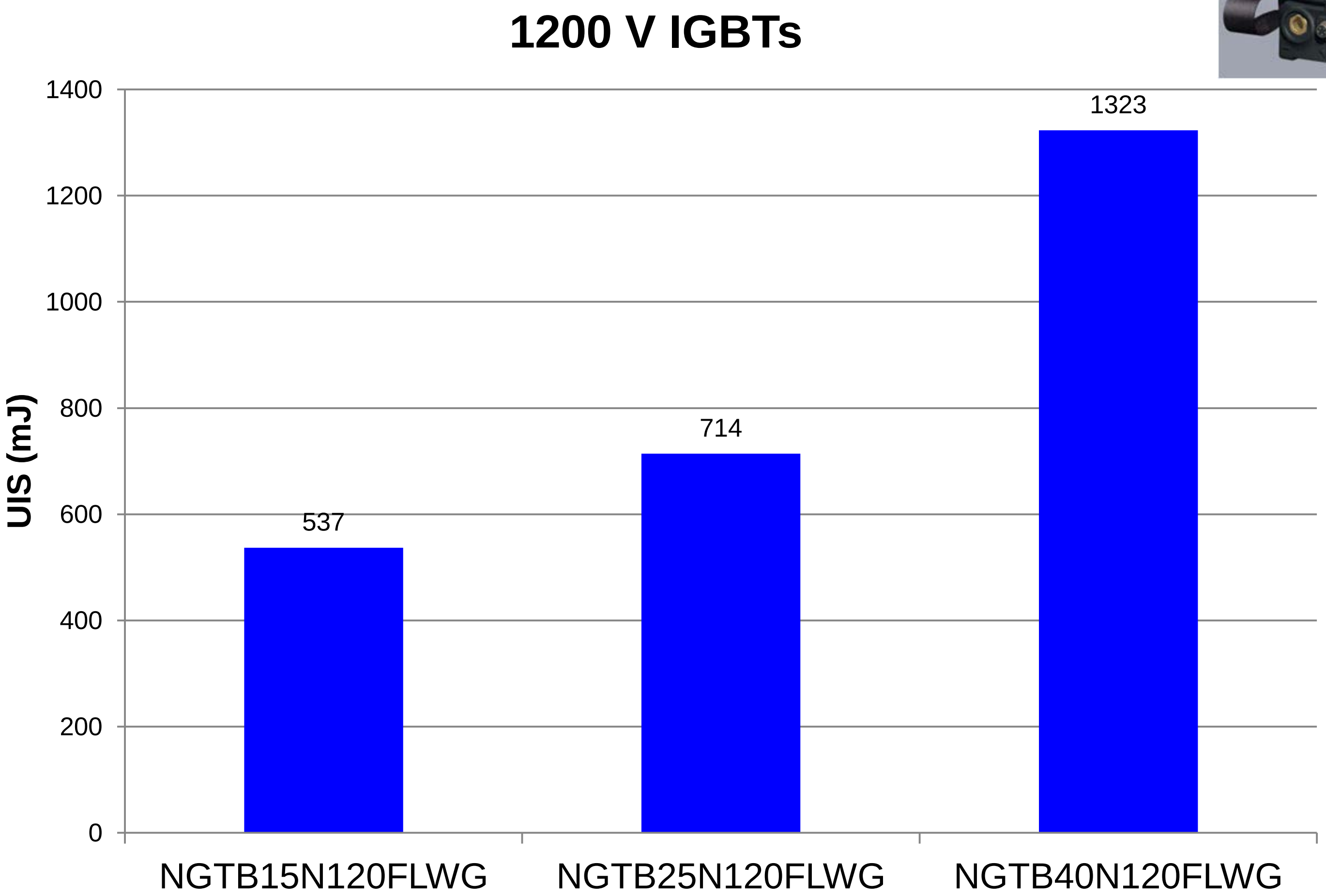
V_{out} = 20 V + 0.04Ω x I (A) MMA (Arc)

V_{out} = 10 V + 0.04Ω x I (A) TIG

V_{out} = 14 V + 0.04Ω x I (A) MIG

General output voltage load lines for high-frequency welders

UIS capability of 1200 V welding IGBTs



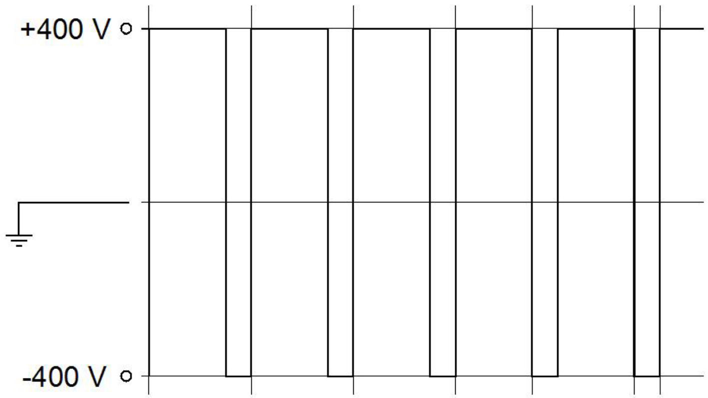
1200 V, Welding IGBTs

Part Number	Release	$V_{CE(sat)}$	Trr	Current	Short Ckt	Package	Tech
NGTB40N120FLWG	**Released**	**1.75**	**250**	**40**	**10**	**TO-247**	**FSI**
NGTB15N120FLWG	Released	1.90	100	15	10	TO-247	FSI
NGTB25N120FLWG	Released	1.70	200	25	10	TO-247	FSI
NGTB40N120FL2WG	**Q2, '13**	**2.00**	**200**	**40**	**10**	**TO-247**	**FSII**
NGTB25N120FL2WG	Q2, '13	2.00	200	25	10	TO-247	FSII
NGTB15N120FL2WG	Q2, '13	2.00	200	15	10	TO-247	FSII

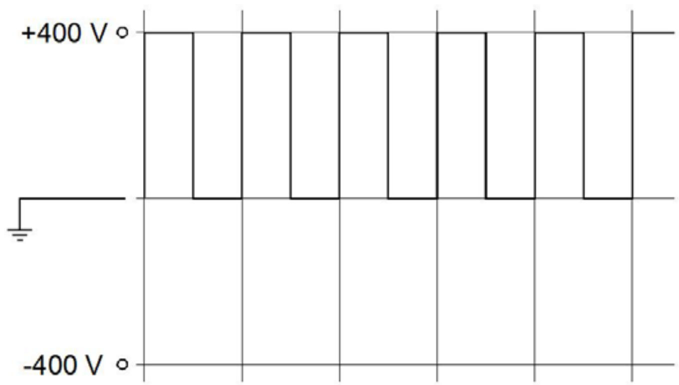
600 V, Welding IGBTs

Part Number	Release	$V_{CE(sat)}$	Trr	Current	Short Ckt	Package	Tech
NGTB30N60FWG	Q4, '12	1.50	189	30	5	TO-247	NPT
NGTB50N60FWG	Q4, '12	1.40	180	50	5	TO-247	NPT
NGTB30N60FLWG	Q4, '12	1.50	100	30	5	TO-247	FS1
NGTB50N60FLWG	**Q4, '12**	**1.50**	**100**	**50**	**5**	**TO-247**	**FS1**
NGTB75N60FL2WG	**Q2, '13**	**1.85**	**80**	**75**	**5**	**TO-247**	**FSII**
NGTB50N60FL2WG	Q3, '13	1.85	80	50	5	TO-247	FSII
NGTB40N60FL2WG	Q3, '13	1.85	80	40	5	TO-247	FSII
NGTB30N60FL2WG	Q3, '13	1.85	80	30	5	TO-247	FSII

Neutral Point Clamp Inverters



H-Bridge 200 V output



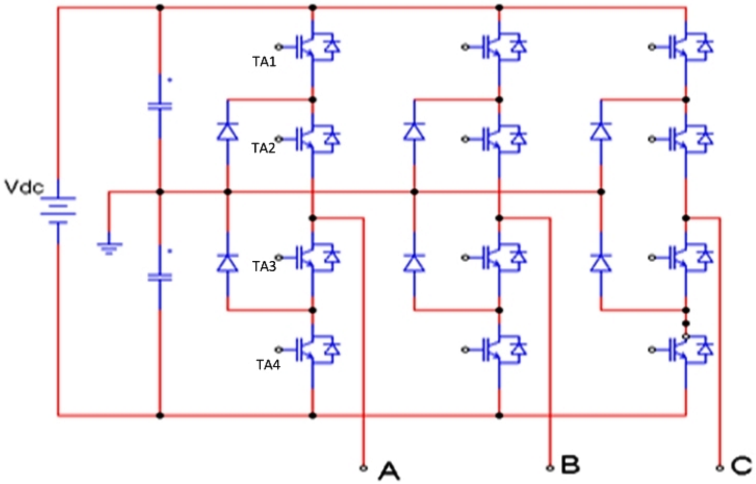
NPC 200 V output

Neutral Point Clamp Topologies

- Better duty ratio resolution
  - H-Bridge, 0 – 400 V 50% - 100% d
  - NPC, 0 – 400 V 0% - 100% d
- Lower switch transition voltage
- Lower voltage ratings on some/all switches
- Higher semiconductor count

Inverter Topologies – NPC, 3-level

Solar Inverters

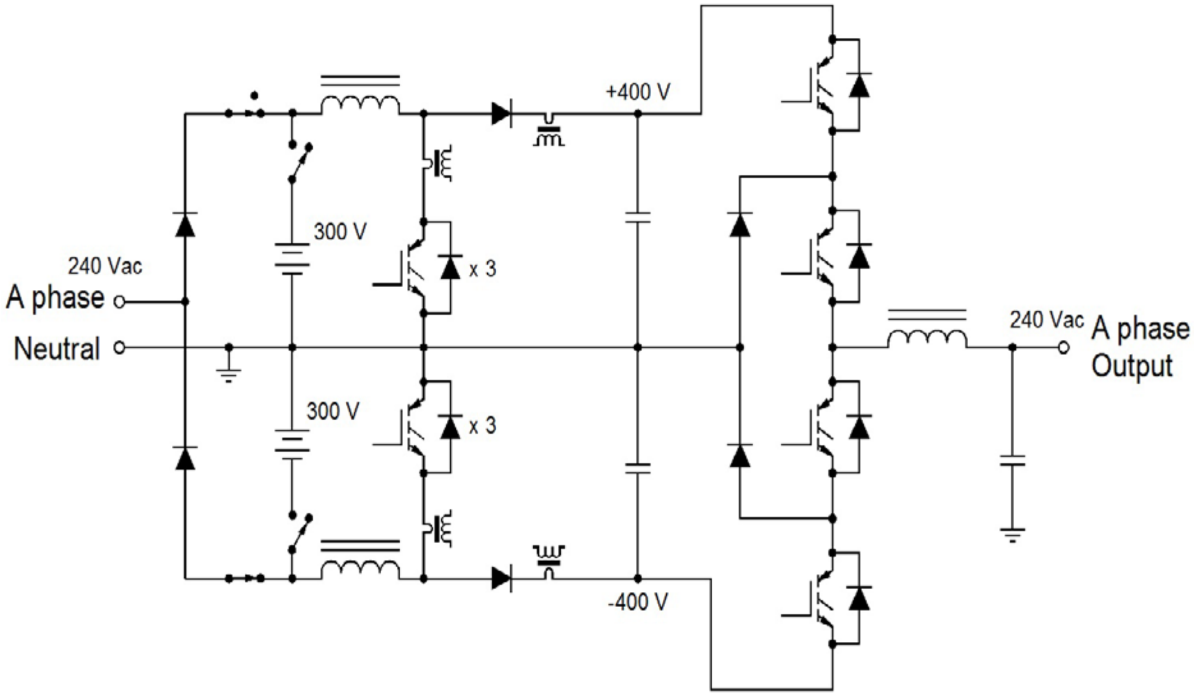


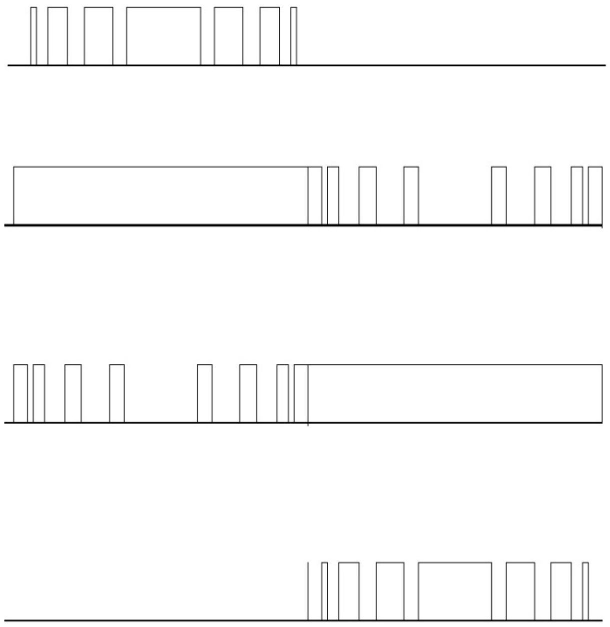
3-level, NPC, Inverter

- **Motor Drives**
- **UPS**
- **Solar Inverters**

- Efficient topology
- Good at medium to high power levels
- Power switches see half input voltage
- Switching losses are reduced due to lower voltage at transition
- Two switches operate at the switching frequency and *two at fundamental frequency*

Three Level Inverter with PFC

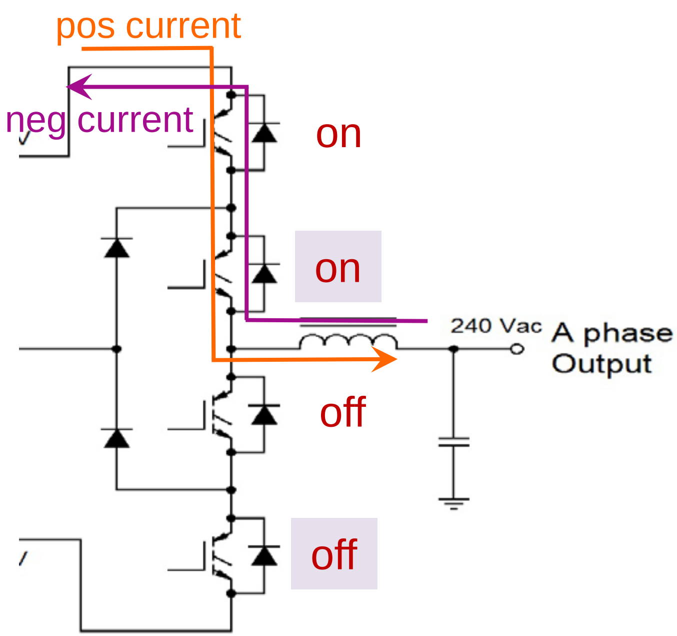




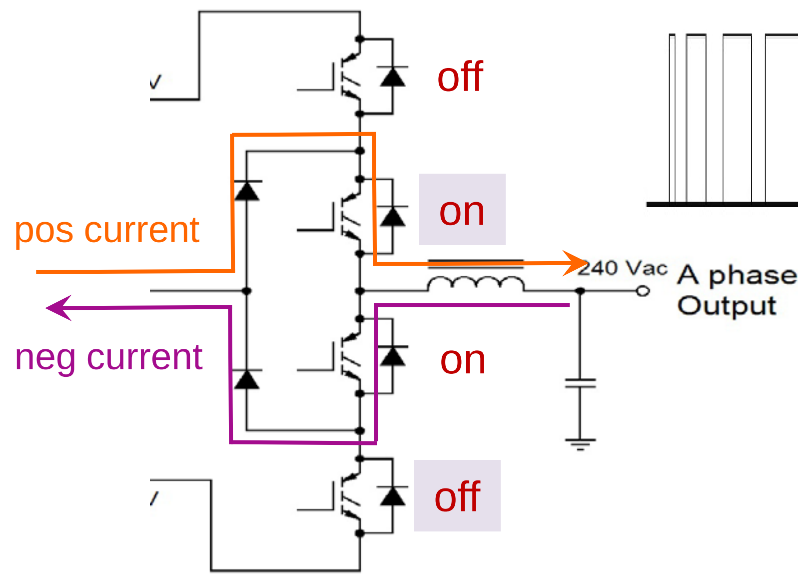
Gate drive waveforms

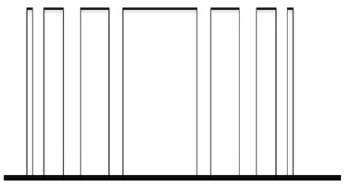
Neutral Point Clamp Inverter

Positive half sine wave operation



High voltage





Neutral

For each half sine cycle, two of the switches are static and two are PWMed.

Three Level Inverter with PFC

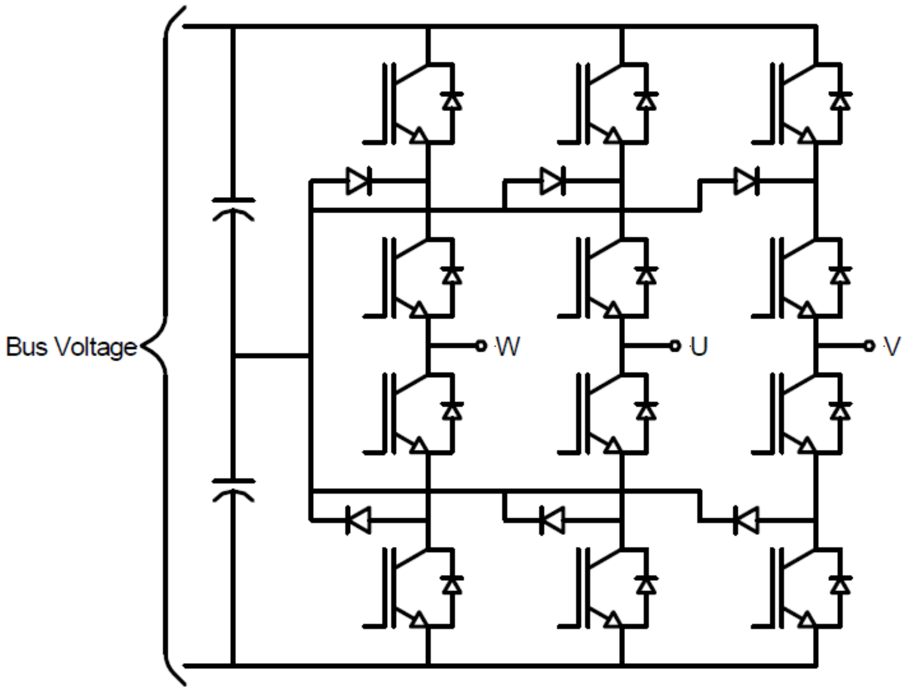
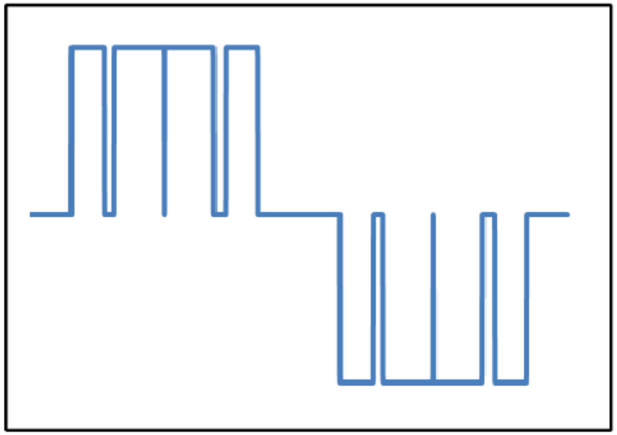
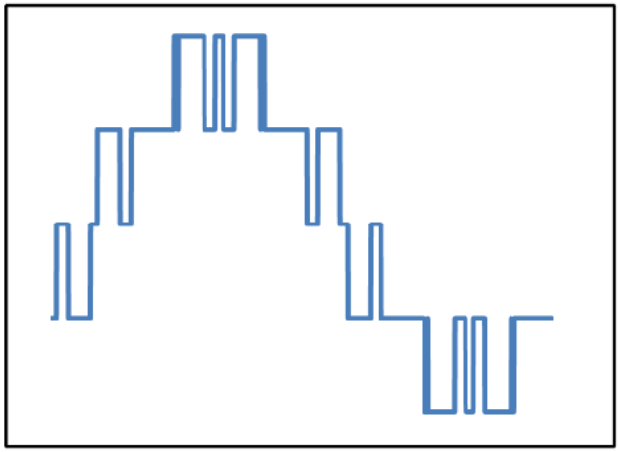


Figure 1. NPC Inverter



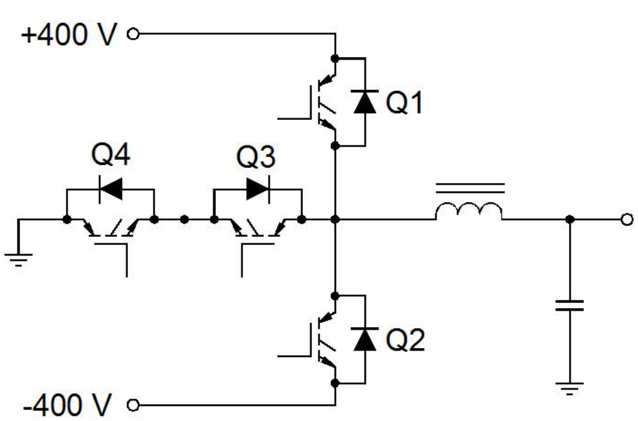
Leg voltage waveform



Phase-to-phase

Inverter Topologies – NPC, T-Type

UPS



T-Type, NPC, Inverter

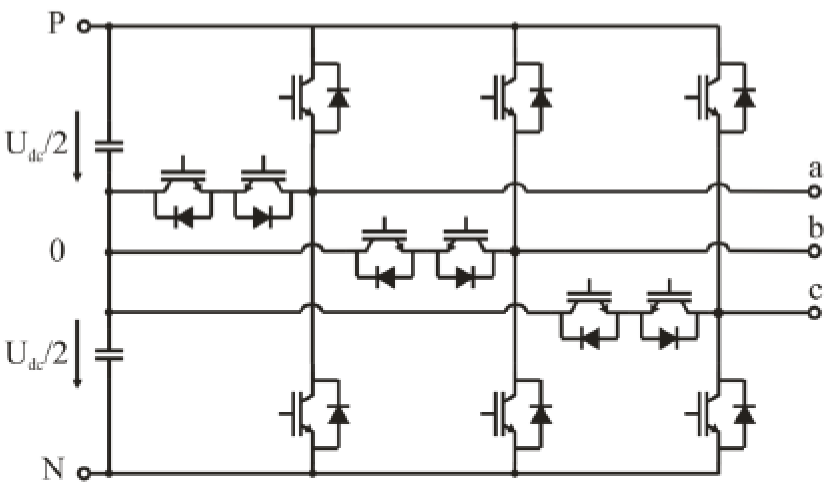
- **Motor Drives**
- **UPS**
- **Solar Inverters**

- Efficient topology
- Good at medium to high power levels
- Q1 & Q2 see full input voltage
- Q3 & Q4 see half input voltage
- Switching losses are reduced due to lower voltage at transition
- Two switches operate at the switching frequency and *two at fundamental frequency*

Inverter Topologies – NPC, T-Type

Solar Inverters

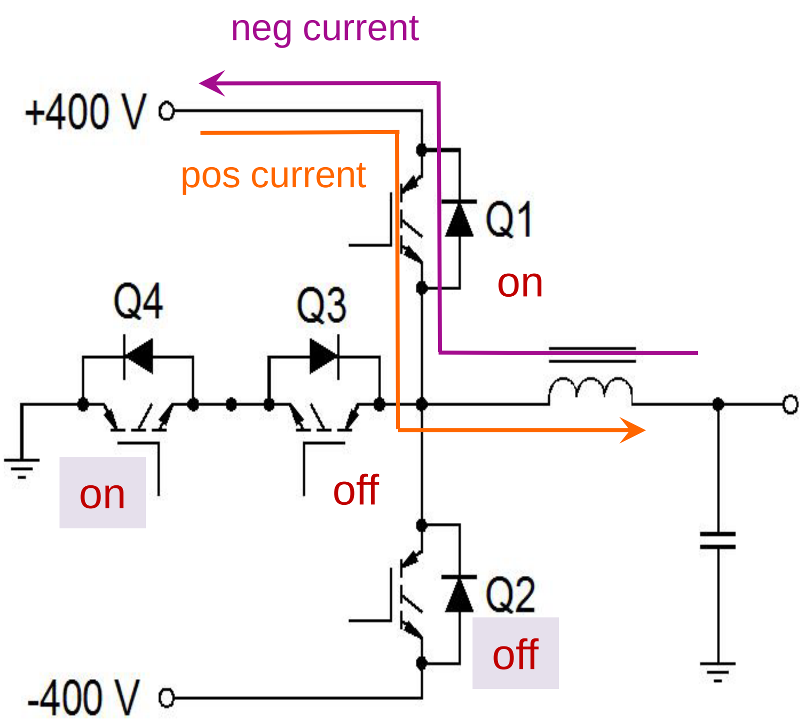
- **Motor Drives**
- **UPS**
- **Solar Inverters**



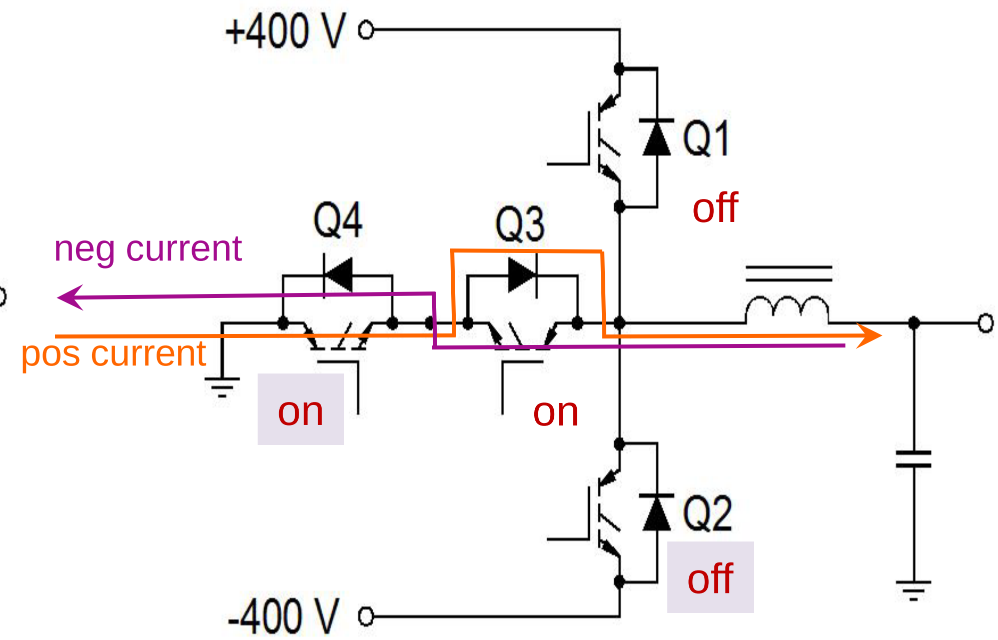
T-Type, NPC, Inverter

- Efficient topology
- Good at medium to high power levels
- Power switches see half input voltage
- Switching losses are reduced due to lower voltage at transition
- Two switches operate at the switching frequency and *two at fundamental frequency*

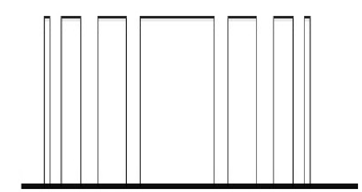
Inverter Topologies – NPC, T-Type



High voltage



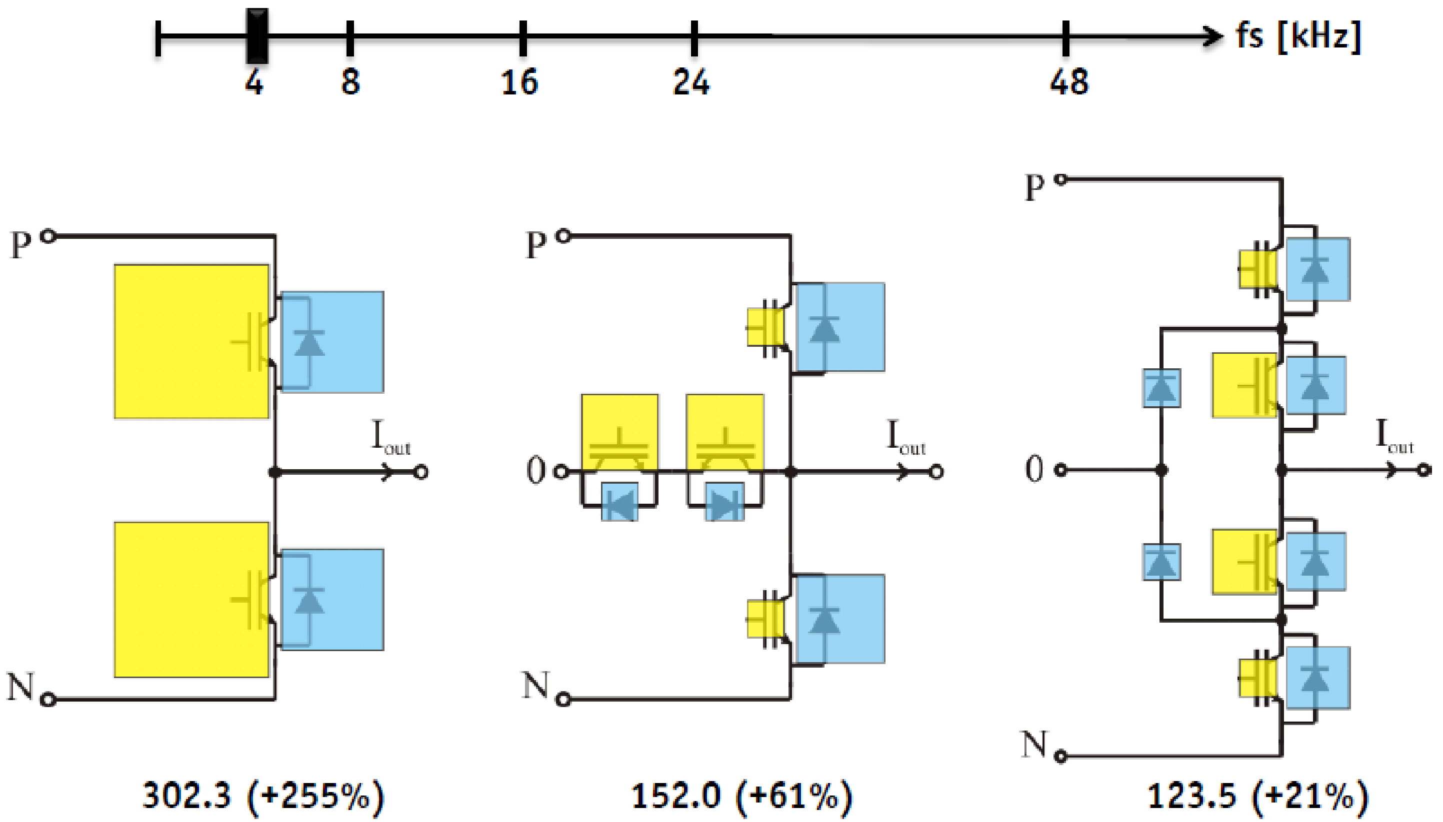
Neutral



Inverter Topologies

Necessary chip area for Tj=125°C (**rectifier operation**)

Switching frequency



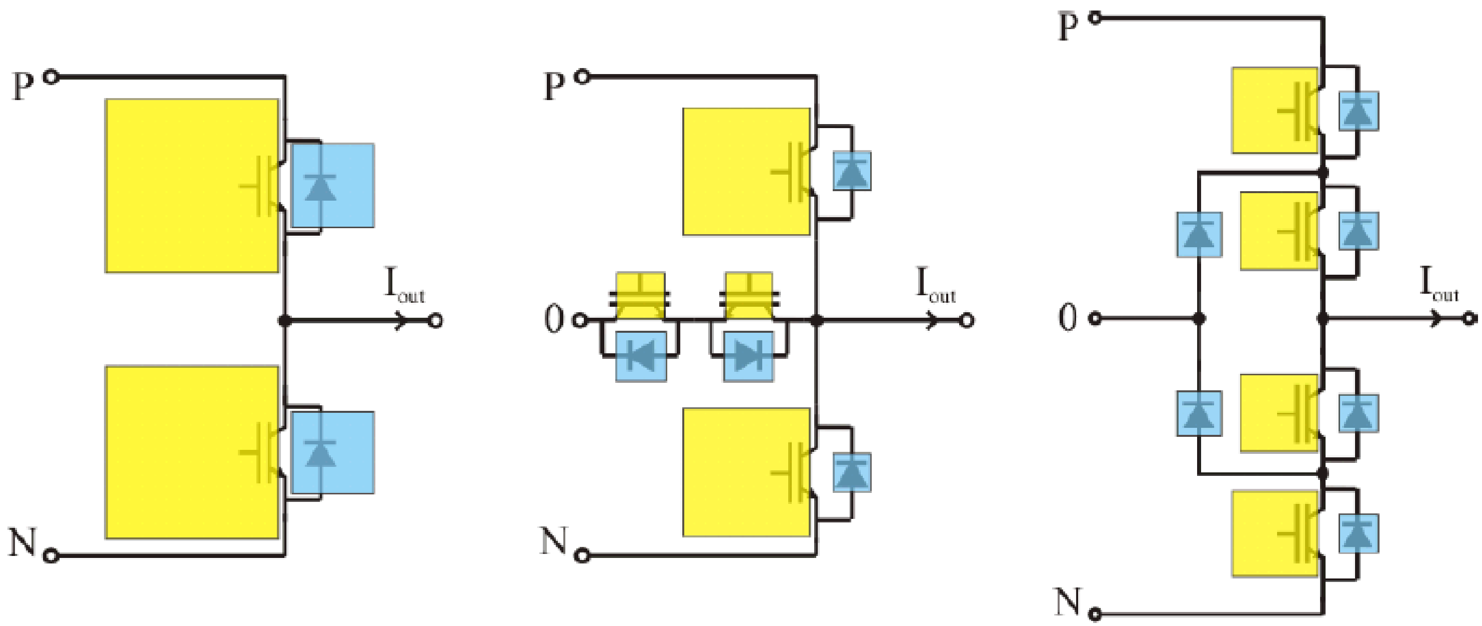
Total die area [mm^2] (3 phases)

Source: Comparative Evaluation of Advanced 3-Level Inverter/Converter Topologies Against 2-Level Systems, Power Electronic Systems Laboratory, M. Schweizer, T. Friedli, J.W. Kolar,

Inverter Topologies

Necessary chip area for Tj=125°C (**Inverter operation**)

Switching frequency



303.4 (+209%) | 185.2 (+64%) | 150.6 (+17%)

Total die area [mm^2] (3 phases)

Source: Comparative Evaluation of Advanced 3-Level Inverter/Converter Topologies Against 2-Level Systems, Power Electronic Systems Laboratory, M. Schweizer, T. Friedli, J.W. Kolar,

Optimization results for Tj = 125°C

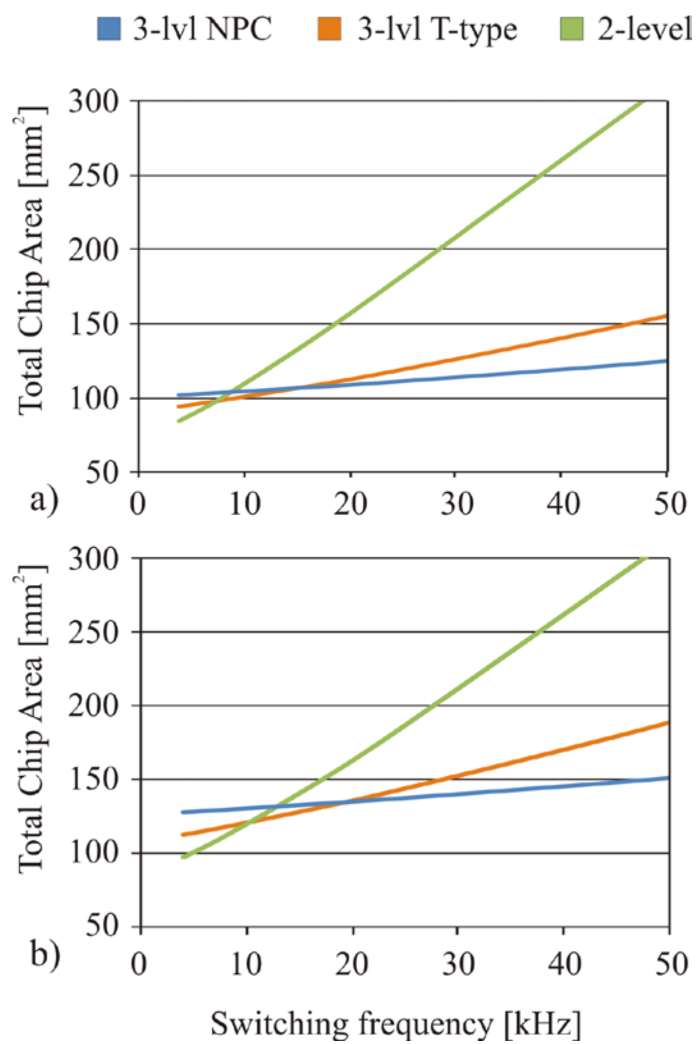
2-level topology

- Losses are *concentrated* in few chips
- Chip size increases sharply with frequency
- Total chip area of 2-level is smallest only for low switching freq. (fs < 10 kHz)!

•3-level topologies

- Losses are *distributed* over many semiconductors
- Chip size reduction possible
- Losses increase only slightly with fs
- Distinct loss profile (Operating point)
- Total semiconductor area:

for f_s=35 kHz: $A_{2\text{-level}} \approx 2^*A_{3\text{-lvl NPC}}$!



Source: Comparative Evaluation of Advanced 3-Level Inverter/Converter Topologies Against 2-Level Systems, Power Electronic Systems Laboratory, M. Schweizer, T. Friedli, J.W. Kolar,

Inverter Topologies

Simple Efficiency Comparison

2-level is efficient for low switching frequency

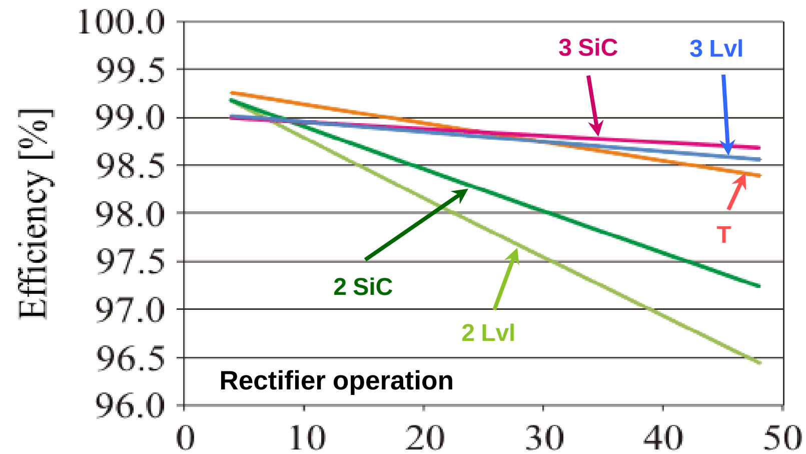
- SiC diodes can extend fs range

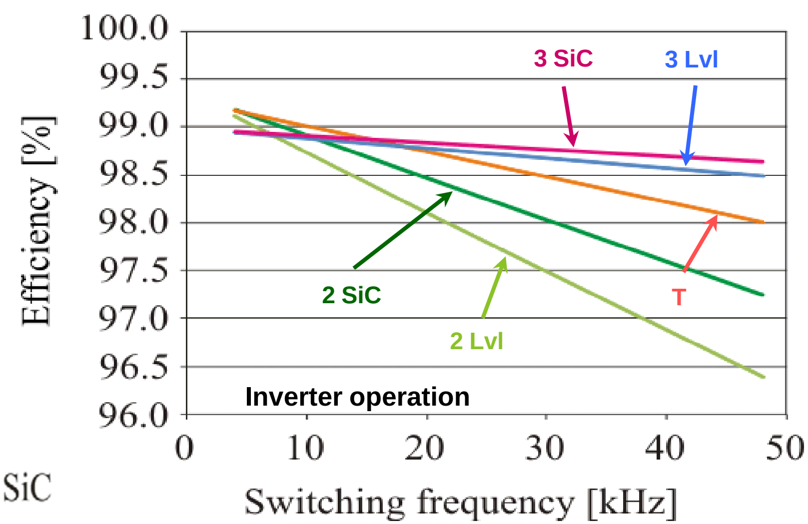
T-type topology is very efficient for medium fs (8 – 20 kHz)

3-level NPC efficiency has flattest dependency on fs

- Suitable for high fs
- SiC diodes make only sense for very high fs (>50 kHz)

Pn = 10kW, Udc=700V, Ûn=325V, În=20.5A, j=0/180°





2-level 2-level SiC 3-lvl T-type 3-lvl NPC 3-lvl NPC SiC

Power Management

ON Semiconductor®

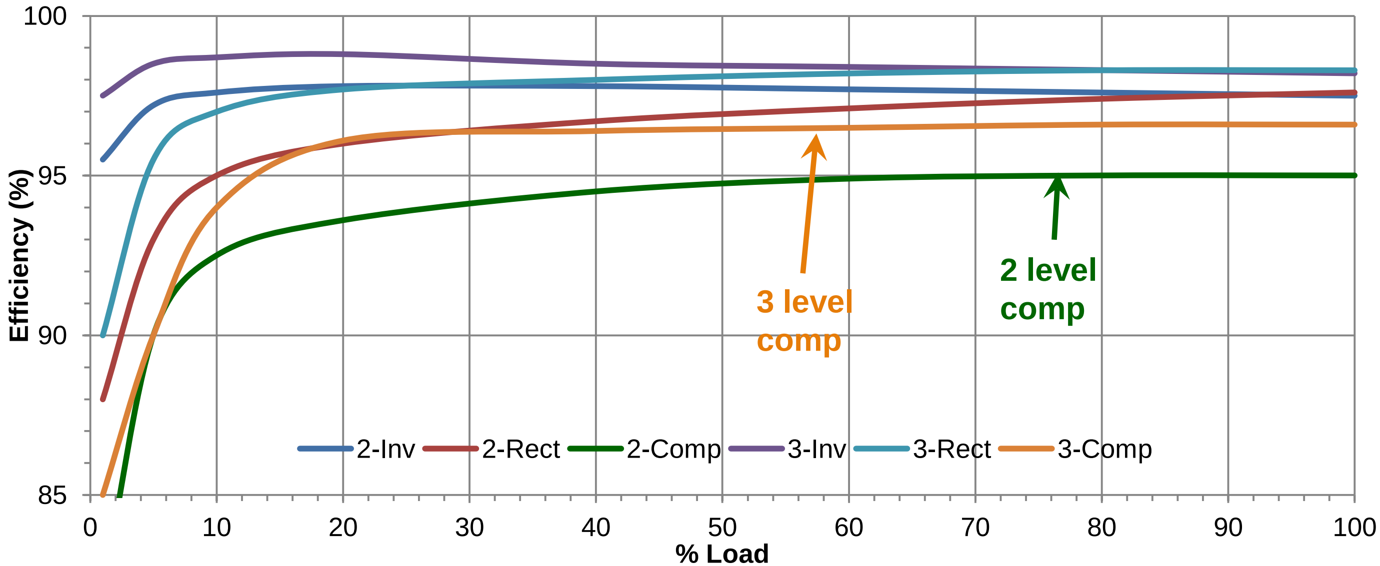
Five Years Out

Source: Comparative Evaluation of Advanced 3-Level Inverter/Converter Topologies Against 2-Level Systems, Power Electronic Systems Laboratory, M. Schweizer, T. Friedli, J.W. Kolar,

Efficiency Comparison

3-Level NPC inverter compared to an H-bridge inverter

50 kW, three phase inverter
f_{sw} = 10 kHz



Source: Two-Level and Three-Level Converter Comparison in Wind Power Application, Lappeenranta University of Technology, M. Ikonen, O. Laakkonen, M. Kettunen,

Summary

- 3 – Level topologies are more energy efficient than 2 – Level.
- 3 – Level topologies require more semiconductor devices but not necessarily more die area.
- Inverter efficiency normally decreases with switching frequency.
- The data are uncertain for motor efficiency vs. switching frequency.

Characterization vs. Bench Testing

Characterization vs. Bench Testing

ELECTRICAL CHARACTERISTICS (T_J = 25°C unless otherwise specified)

Parameter	Test Conditions	Symbol	Min	Typ	Max	Unit
STATIC CHARACTERISTIC						
Collector–emitter breakdown voltage, gate–emitter short–circuited	V_{GE} = 0 V, I_C = 500 μA	$V_{(BR)CES}$	600	–	–	V
Collector–emitter saturation voltage	V_{GE} = 15 V, I_C = 50 A V_{GE} = 15 V, I_C = 50 A, T_J = 150°C	V_{CEsat}	1.25 –	1.45 1.7	1.7 –	V
Gate–emitter threshold voltage	V_{GE} = V_{CE}, I_C = 350 μA	$V_{GE(th)}$	4.5	5.5	6.5	V
Collector–emitter cut–off current, gate–emitter short–circuited	V_{GE} = 0 V, V_{CE} = 600 V V_{GE} = 0 V, V_{CE} = 600 V, T_J = 150°C	I_{CES}	– –	– –	0.5 2	mA
Gate leakage current, collector–emitter short–circuited	V_{GE} = 20 V , V_{CE} = 0 V	I_{GES}	–	–	200	nA
DYNAMIC CHARACTERISTIC						
Input capacitance	V_{CE} = 20 V, V_{GE} = 0 V, f = 1 MHz	C_{ies}	–	7300	–	pF
Output capacitance		C_{oes}	–	275	–	
Reverse transfer capacitance		C_{res}	–	170	–	
Gate charge total	V_{CE} = 480 V, I_C = 50 A, V_{GE} = 15 V	Q_g	–	310	–	nC
Gate to emitter charge		Q_{ge}	–	60	–	
Gate to collector charge		Q_{gc}	–	150	–	

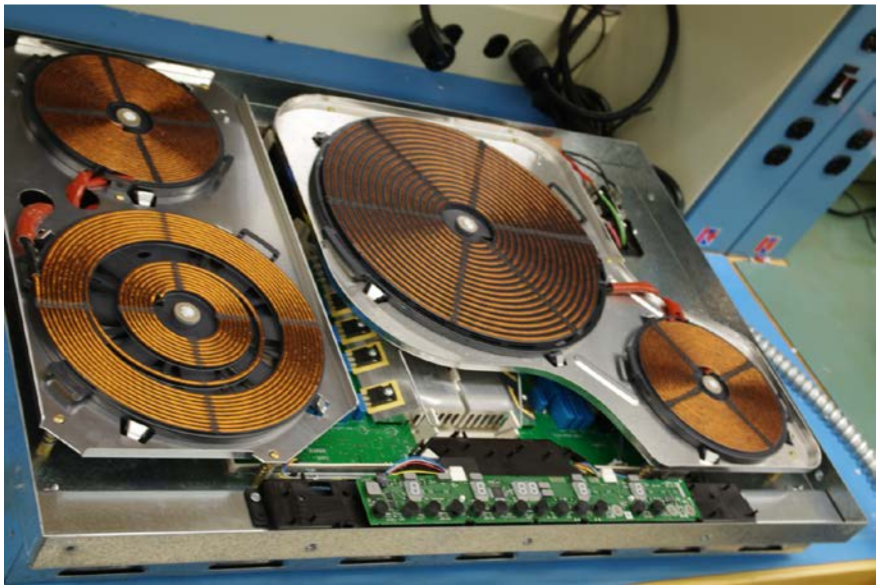
Characterization data is collected under a standard set of conditions and is useful for comparing and selecting parts

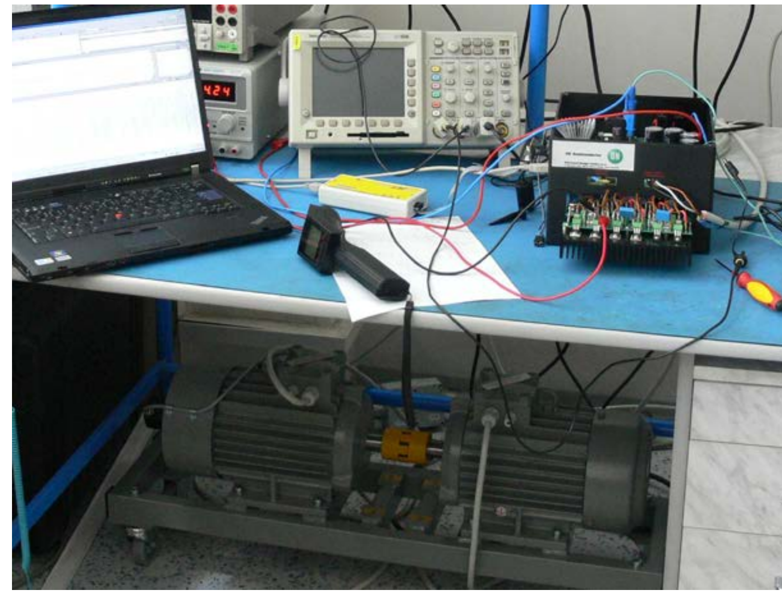
For V_{CEsat} V_{GE} = 15 V is std, I_C is at the rated current, and in this case both 25°C and the maximum rated temp (150°C) have been tested.

Characterization vs. Bench Testing

System Testing

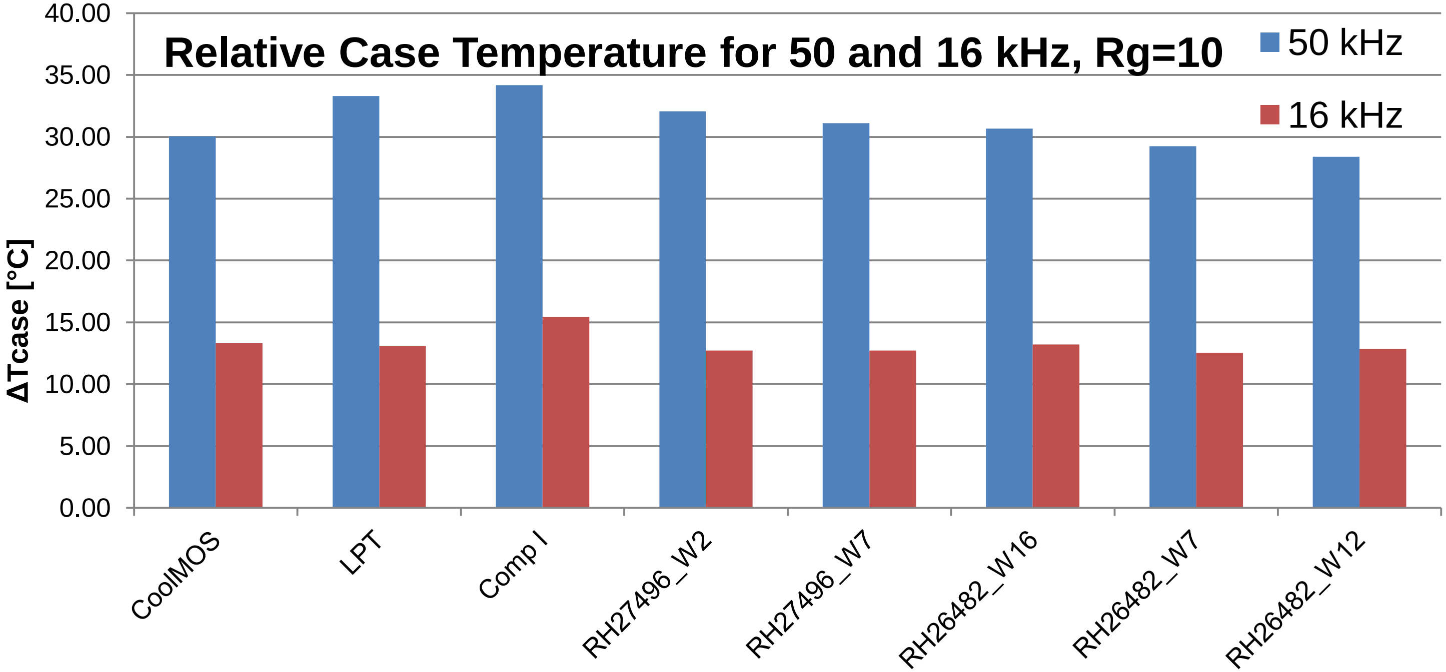
The overall efficiency of a power transistor is a key factor in the selection process.



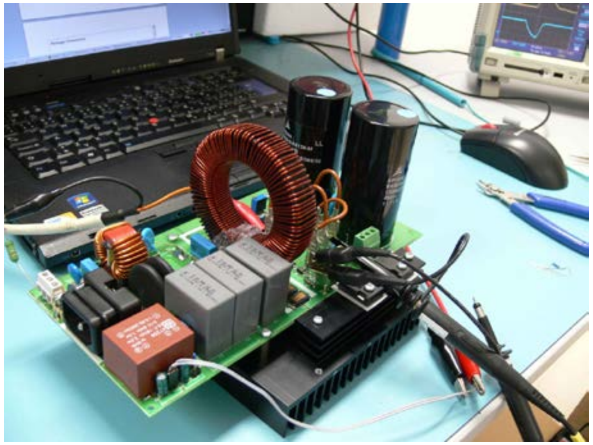


One system is not representative of all systems but does provide valuable insight into the operation of a part under real conditions.

Characterization vs. Bench Testing

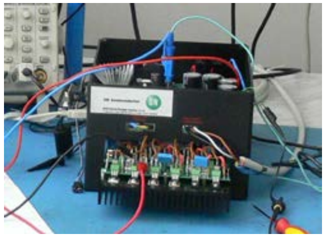


Test results for PFC system testing. This unit was tested with a 3 kW output level and at two switching frequencies.

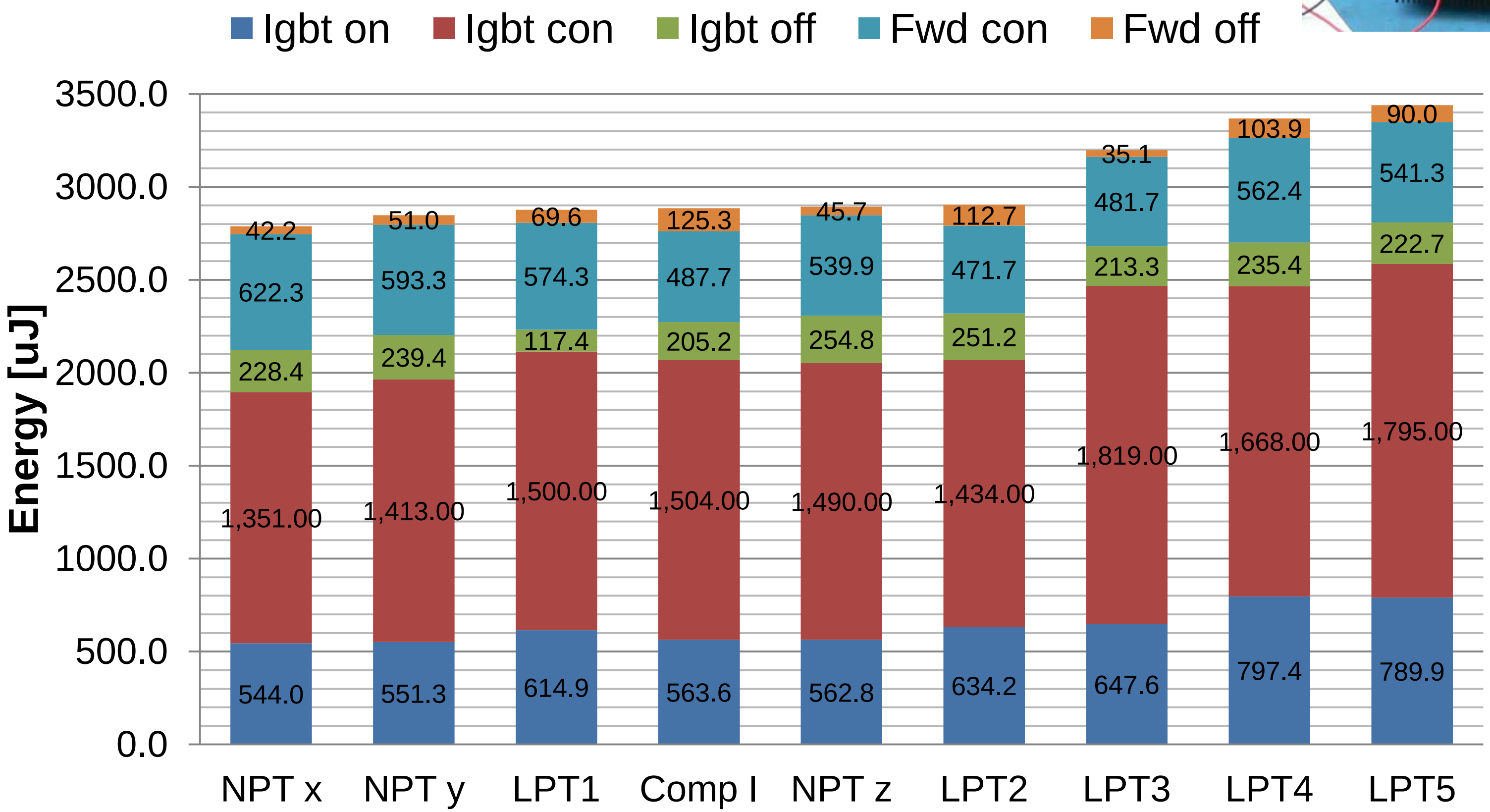


Characterization vs. Bench Testing

Testing process variations for a 15 A, 600 V, motor drive IGBT



Device Energy Losses distribution chart 1



V_{DC} = 300 V, fs = 10 kHz

Thermal

General Thermal Equation

$$PD = \frac{Tjmax - Tref}{R\Theta JX}$$

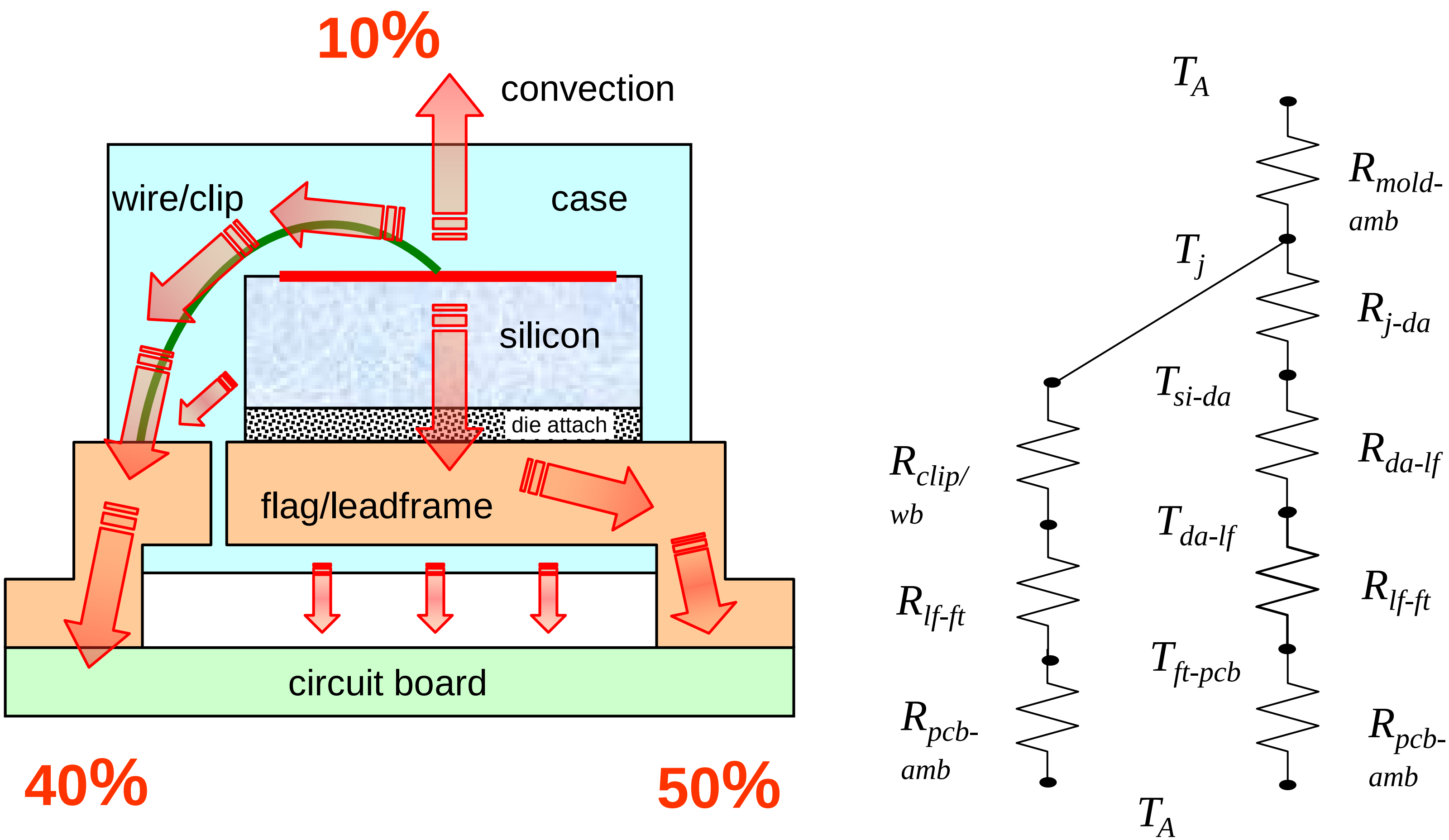
Where:

$Tjmax$ = Maximum junction temperature specified for the device under analysis, usually 150 ^{0}C for power MOSFETS.

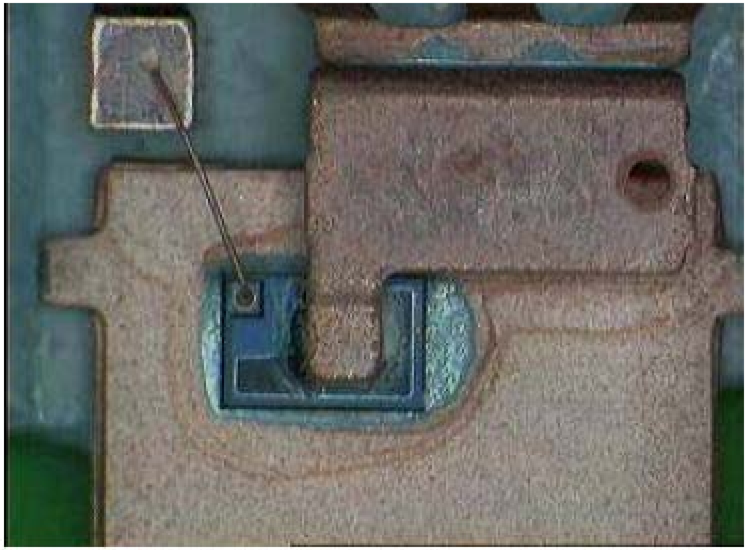
$Tref$ = Reference temperature, usually the ambient temperature of your system, usually 25 ^{0}C and 85 ^{0}C .

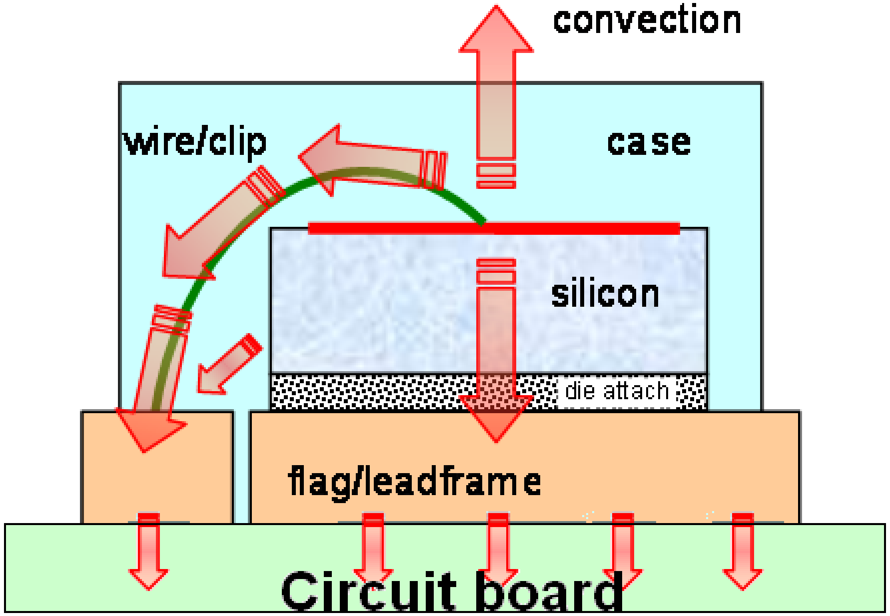
$R\Theta JX$ = Thermal Resistance from Junction-to-X, where X could be Case, Ambient, Foot, Lead, etc.

Typical Package



Typical MOSFET Package



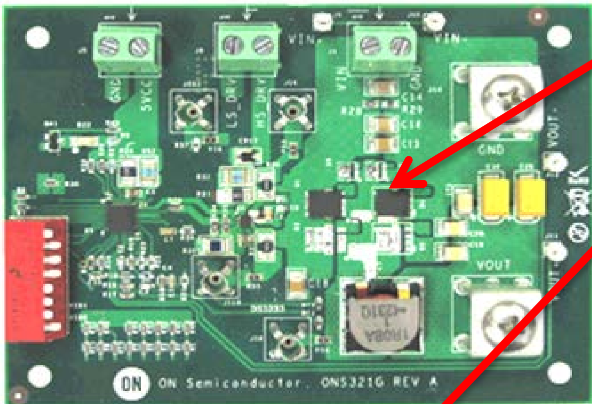


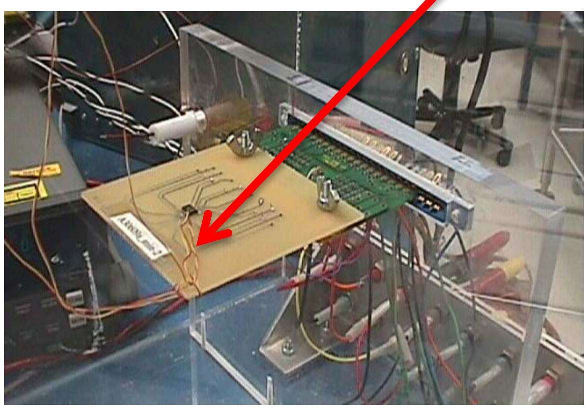
Top view

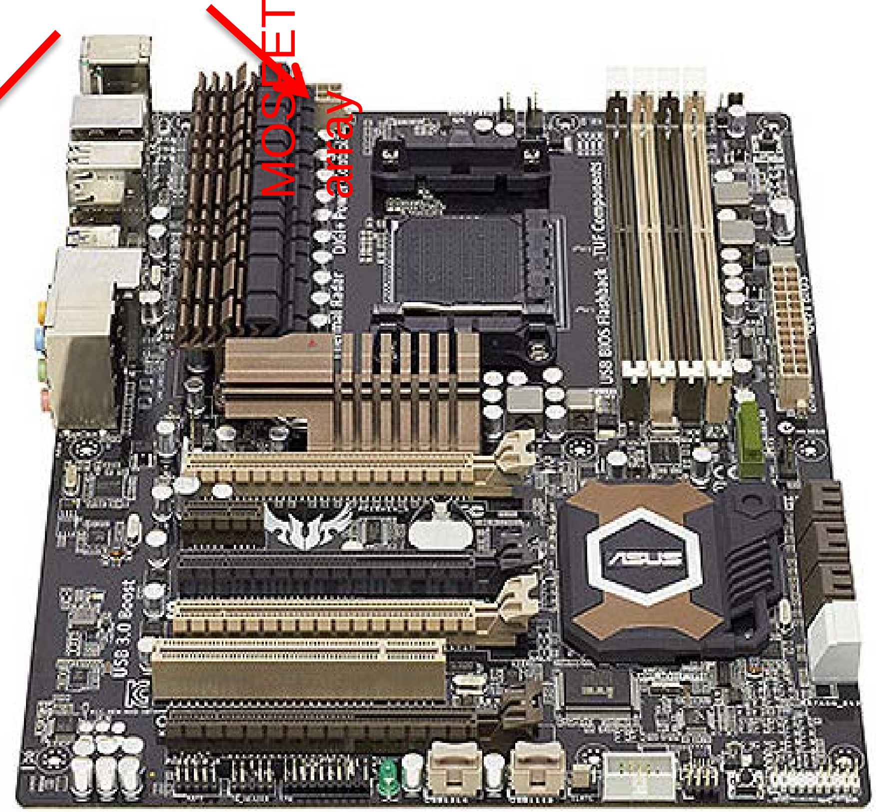
Side view

What's MOSFET RΘ ?

MOSFETS

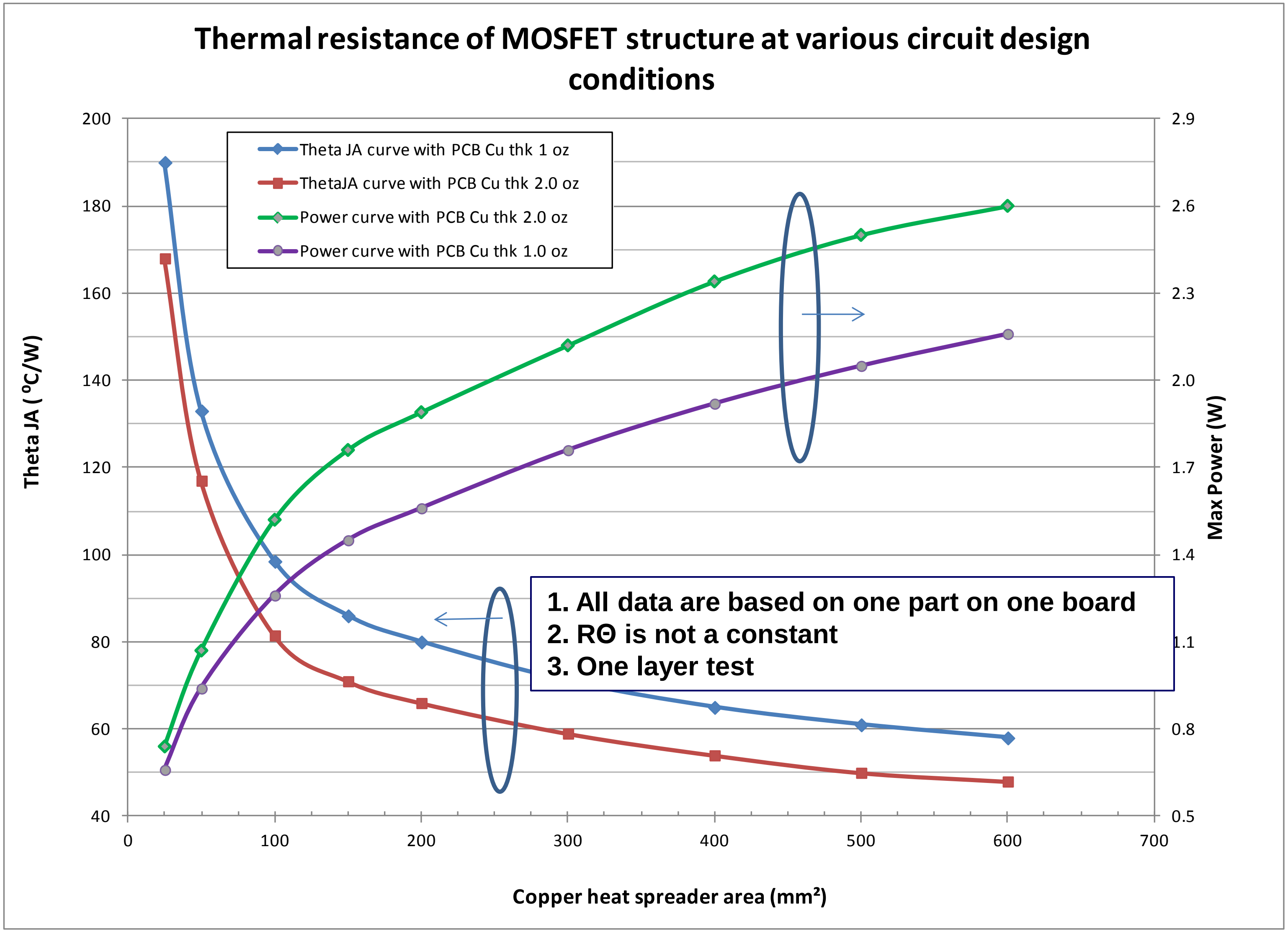






- **Thermal resistance is not a constant**. It strongly depends on package, application circuit, system, and surrounding environment.

Thermal Resistance of MOSFET Structure at Various Circuit Conditions



Basic Optimization Methods for Thermal Resistance

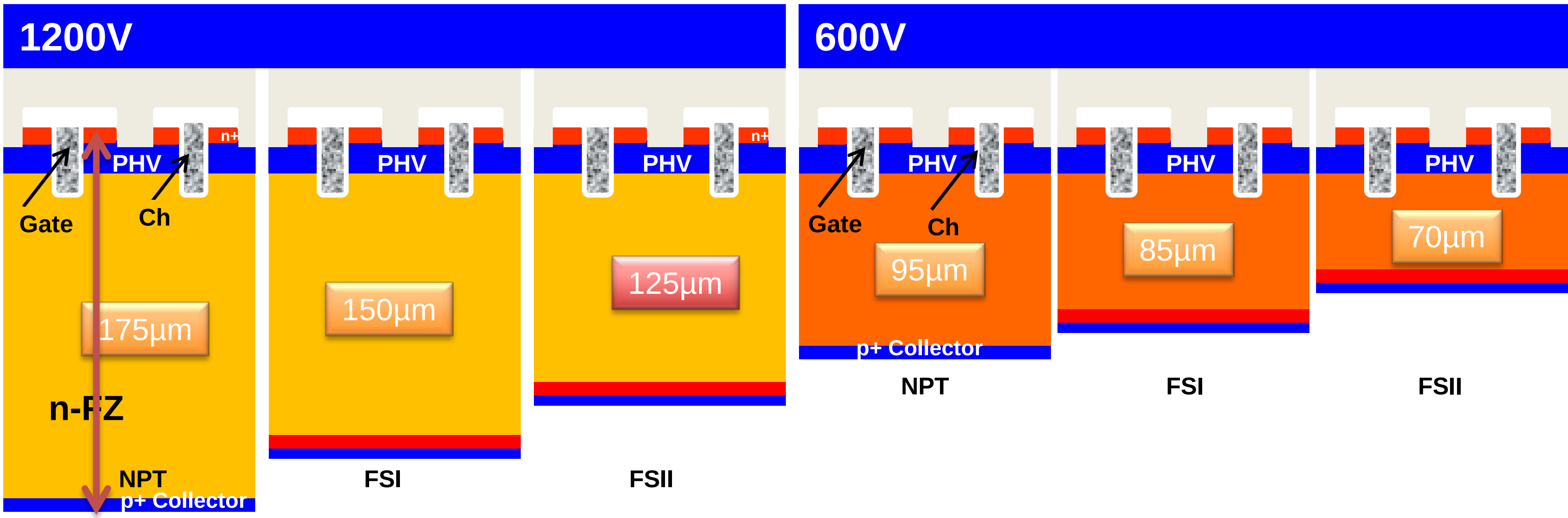
1. Separate power devices on PCB board, Thermal interactions
2. Deposit thicker copper
3. Use more layers
4. Use more vias to spread thermal power
5. Orient heat sink to help hot air flow
6. Use colder air to cool heat sink

Basic Heat Sink Facts

1. Thermal resistance of heat sink is strongly related with surface area
2. Thermal resistance of heat sink is strongly related with surface airflow in application
3. Thermal surface of heat sink is a function of shape and materials
4. No universal equations for thermal resistance calculation for heat sink
5. Specific thermal resistance calculation should refer to heat sink manufacturers' guide

New Trends
IGBTs

NPT, FSI and FSII Trench IGBT



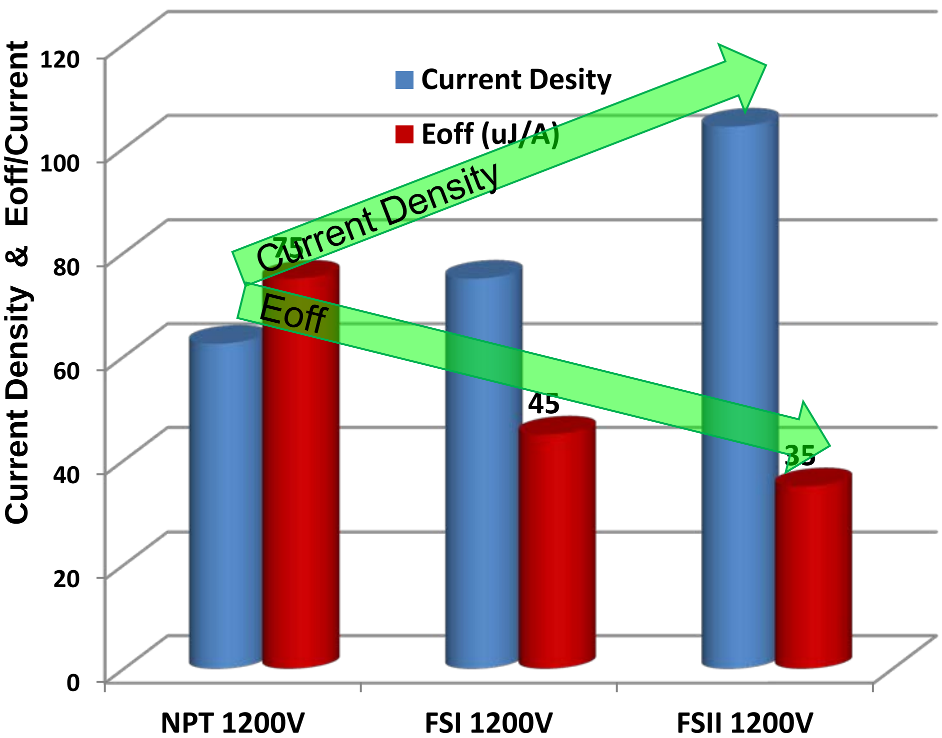
Ultra thin wafer and backside processing is the enabling technology for reducing both conduction and switching power conversion losses

New Trends - IGBTs

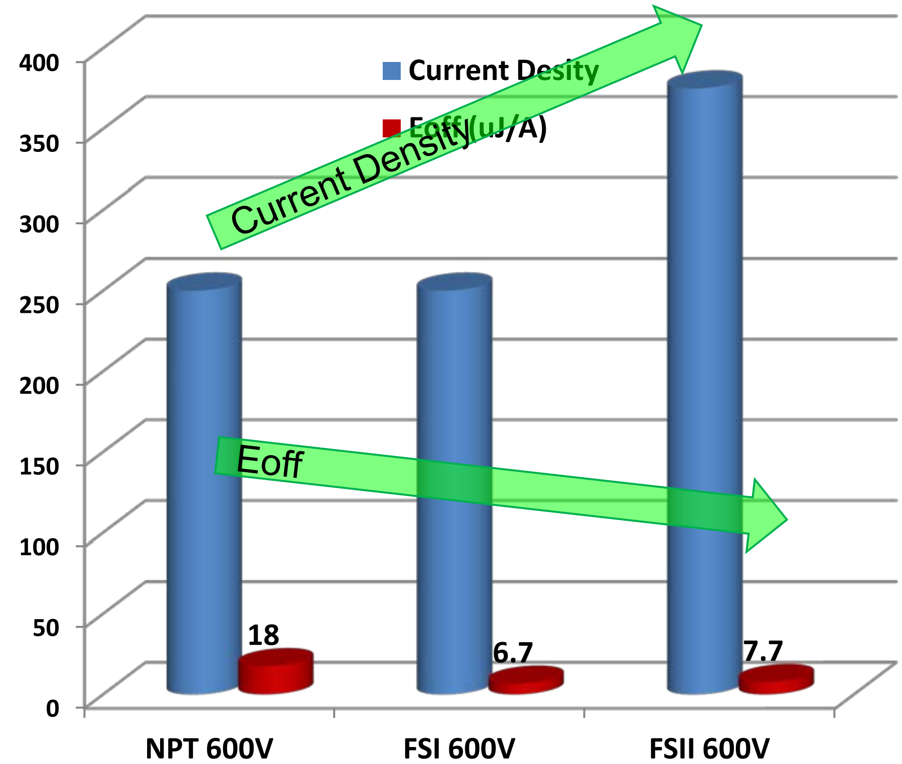
84

NPT, FSI and FSII Trench IGBT
(Assuming VCE(sat) of 1.6V)

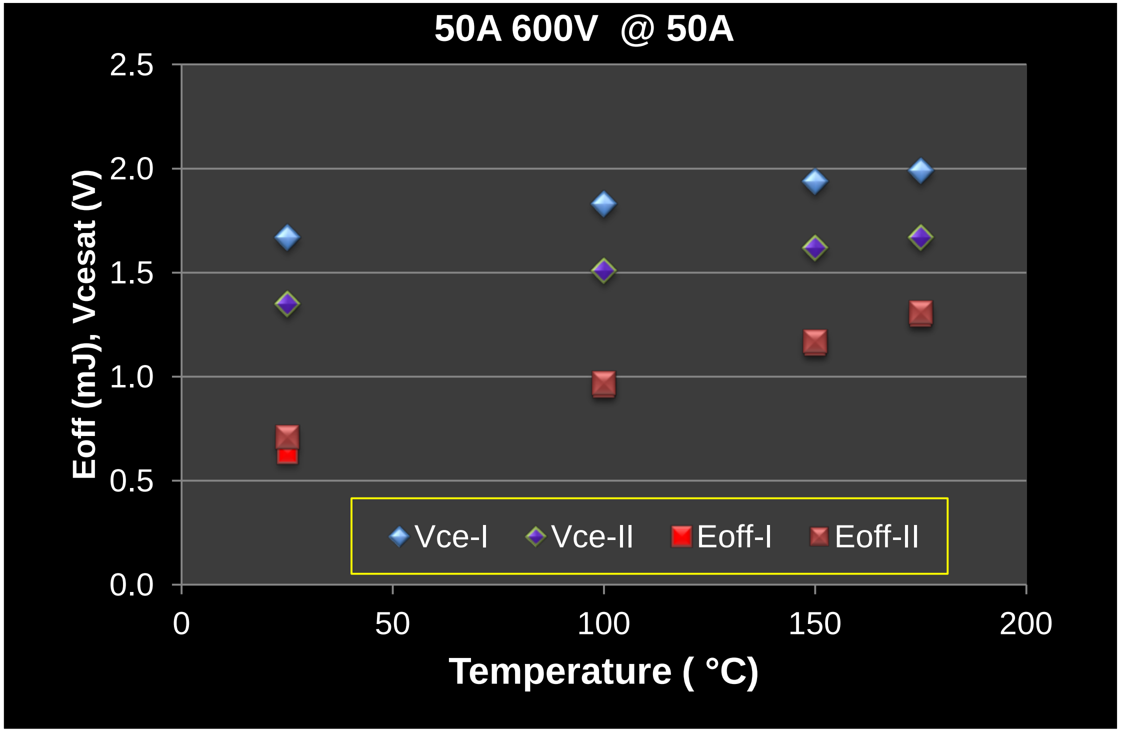
1200V



600V



New Trends - IGBTs



Comparison of Field Stop I to new Field Stop II process.

Switching losses are similar, with significant reduction in conduction losses.

New Trends - IGBTs

NEW DEVICES

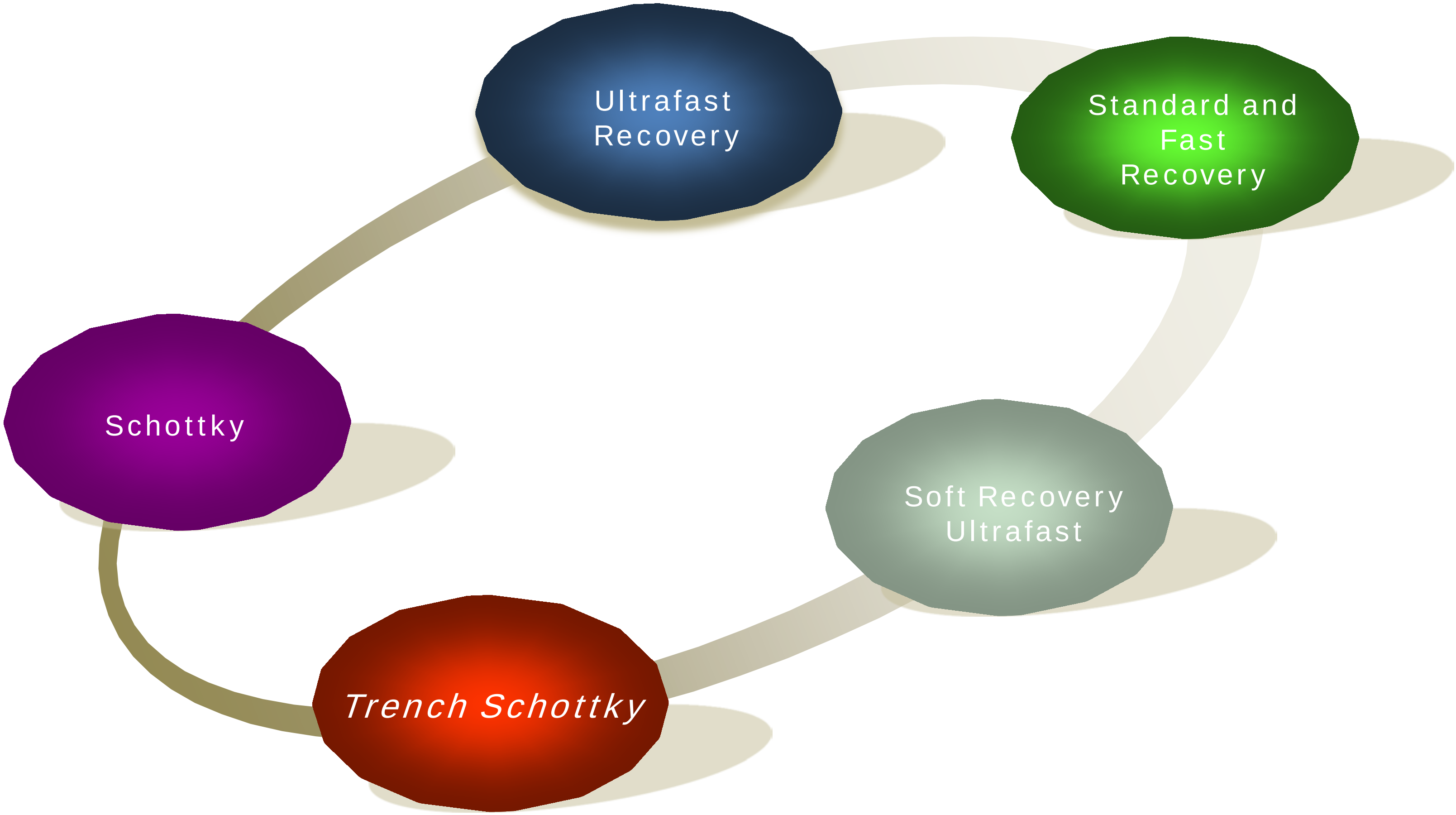
Voltage: 600, 650, 1200, 1350 V

Current: 15 – 75 A

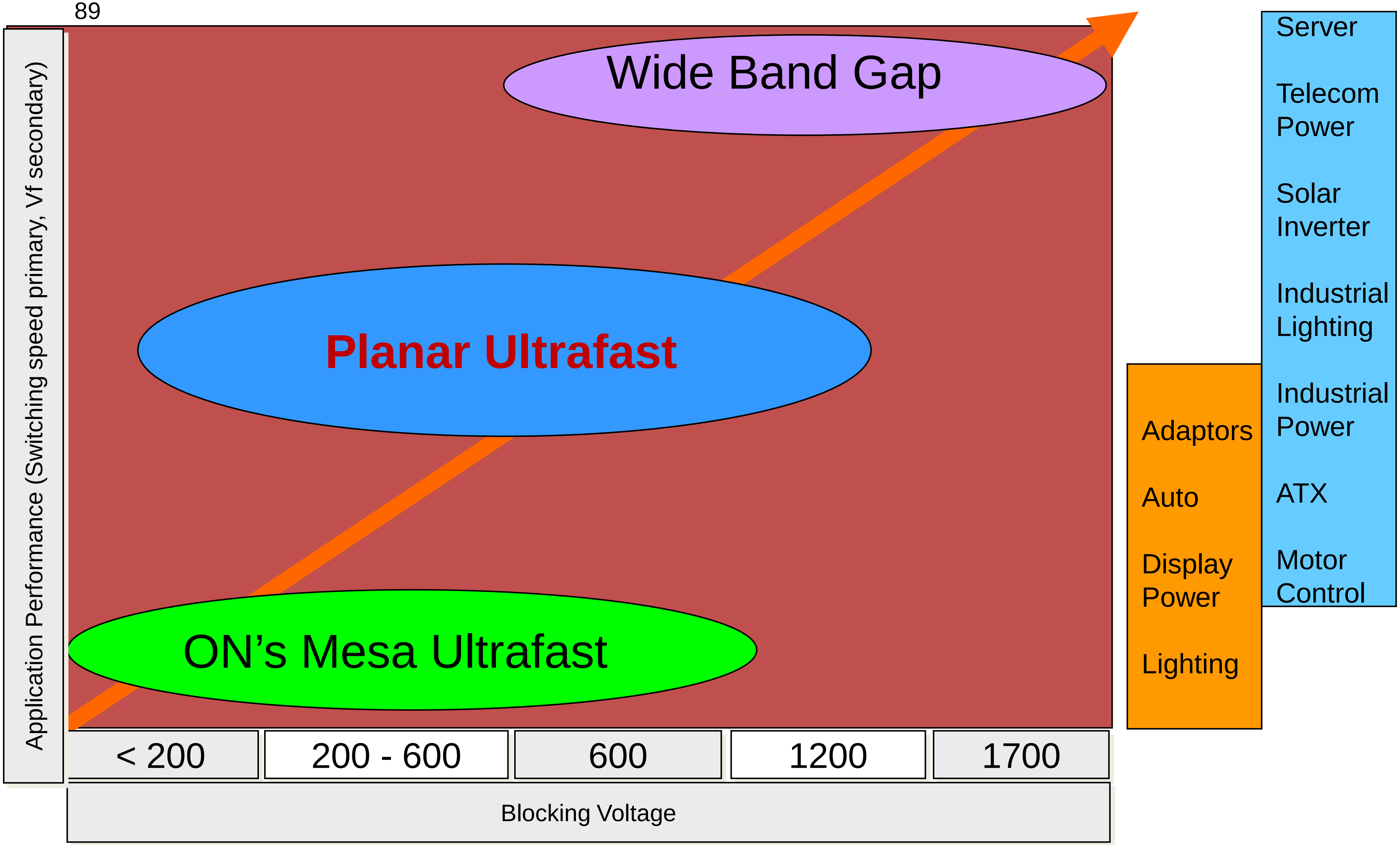
Diodes: None, co-packed, monolithic

New Trends Rectifiers

New Trends - Rectifiers



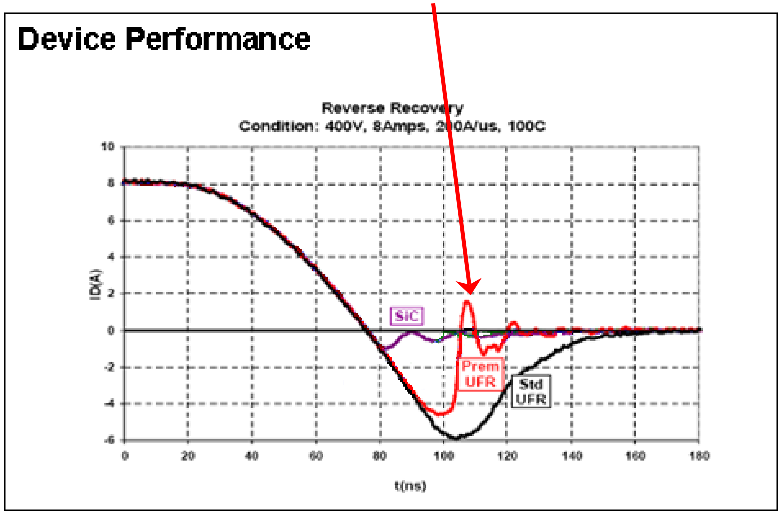
New Trends - Rectifiers



New Trends - Rectifiers

PUF Rectifiers

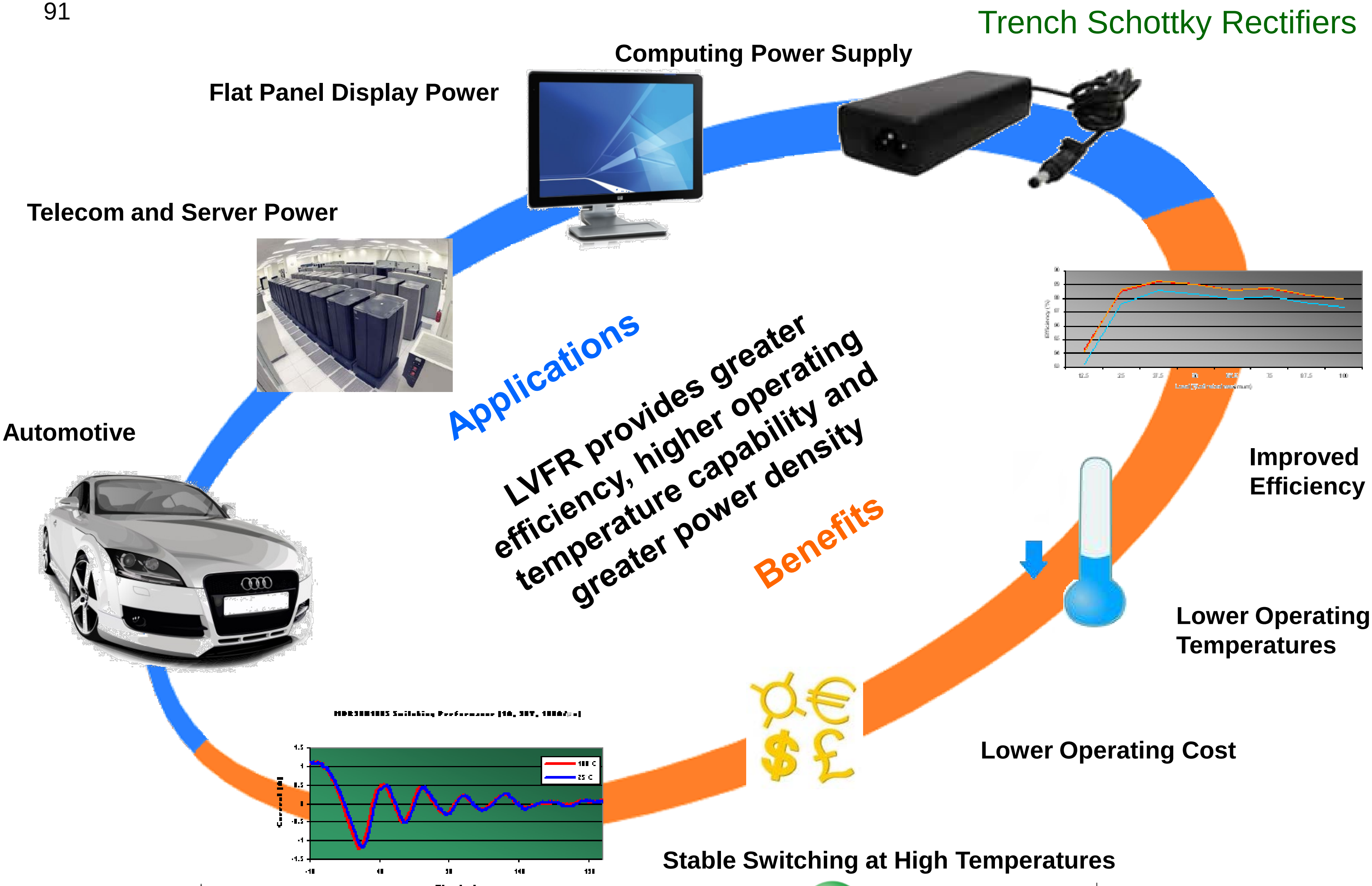
PUF (Planar Ultra Fast) Portfolio



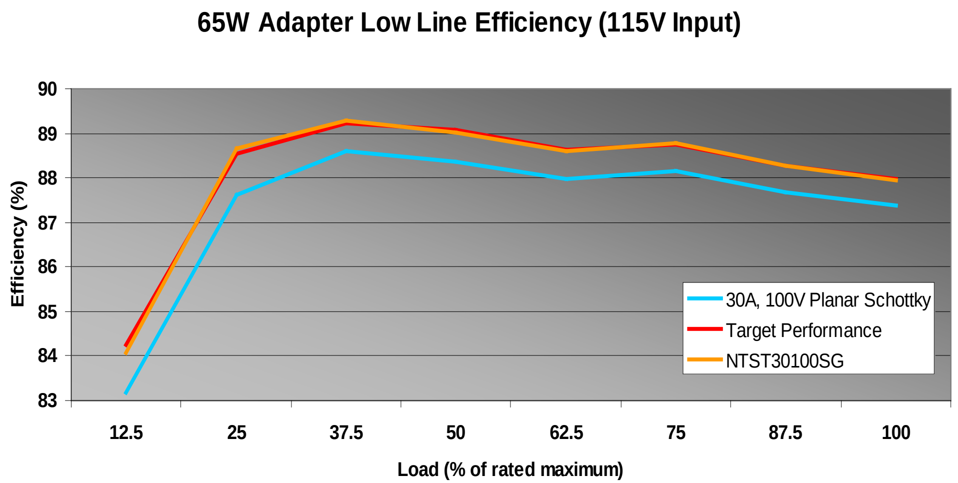
- **Lower losses(reduced trr and qrr), reduced EMI and higher efficiency in hard switching applications.**
- **Planar structure enabling expansion of Ultrafast portfolio in lower height STM packages which was not possible in Standard mesa ultrafast portfolio.**
- **4 devices released YTD. TO220/TO220FP Pkg.**

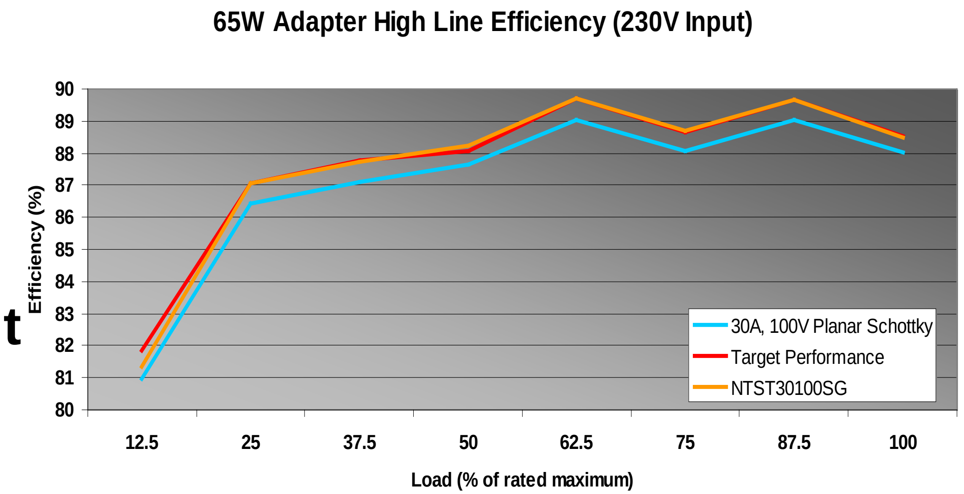
ON Part Number	V_R(V)	If(A)	Status	STM Part Number	Vishay Part Number	NXP Part Number
NHPJ08S600G	600	8	Released.	STTH8R06FP	VS-ETH0806FP-M3	BYC8X-600P
NHPV08S600G	600	8	Released.	STTH8R06D	VS-ETH0806-M3	BYC8-600
NHPJ15S600G	600	15	Released.	STTH15R06FP	VS-ETH1506FP-M3	BYC15X-600
NHPV15S600G	600	15	Released.	STTH15R06D	VS-ETH1506-M3	BYC15-600

New Trends - Rectifiers



Improved Efficiency with Trench Schottky Rectifiers





Energy Conservation Certification
中国节能标志

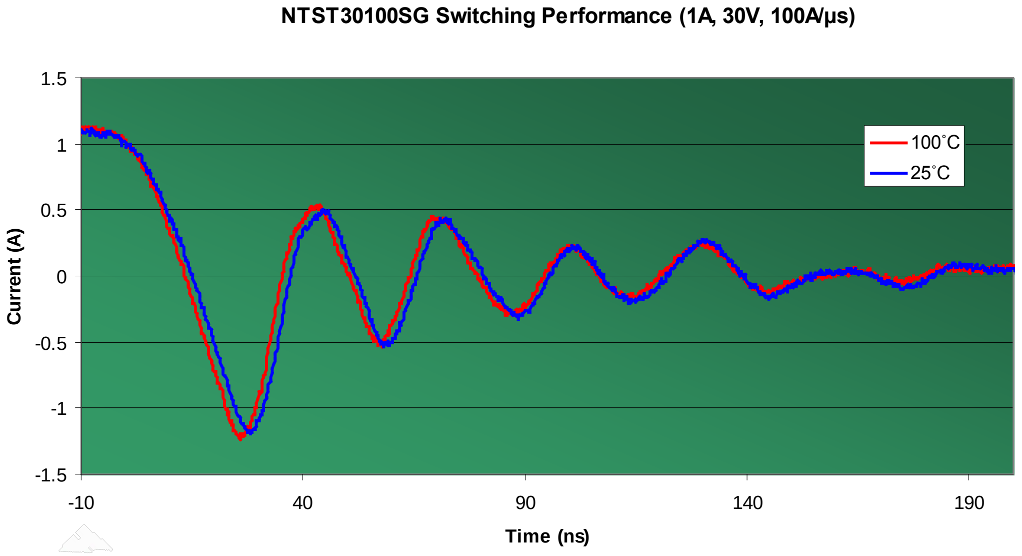
ENERGY STAR

EECA
Energy Efficiency and Conservation Authority
Te Tari Tiaki Pūngao

Ability to meet regulatory requirements without synchronous rectification

Trench Rectifiers: Switching Performance

Stable performance in applications operating over a wide temperature range



Trench Rectifiers provides exceptionally stable switching over temperature

Excellent for automotive power conversion operating in the MHz range

Trench Schottky Rectifiers -Current Portfolio Summary

Device	V_{RRM} (V)	V_F MAX (V)	I_R MAX (uA)	I_O (A)	I_{FSM} (A)	Package(s)
NTSX2080CT	80	0.68 - 0.82	600	20	100-150	TO-220-FP, TO-220
NTSX3080CT	80	0.65 -0.82	700	30	160	TO-220-FP, T0-220
NTS(x)20100CT	100	0.68	800	20	150	I2PAK,D2PAK,TO-220-FP,TO-220
NTSV20100CT	100	0.82	800	20	100	TO-220
NSTV30100SG	100	0.85	1000	30	100	TO-220
NTS(x)30100CT	100	0.68	500	30	160	I2PAK,D2PAK,TO-220,TO-220-FP
NTSV30100CT	100	0.82	500	30	500	TO-220
NTS(x)20120CT	120	0.72- 0.86	700	20	120	I2PAK,D2PAK,TO-220-FP,TO-220
NTS(x)30120CT	120	0.76-0.92	800	30	150	I2PAK,D2PAK,TO-220-FP,TO-220
NTS(x)40100CT	100	0.68	800	40	160	I2PAK,D2PAK,TO-220-FP,TO-220
NTS(x)40120CT	120	0.71	500	40	250	I2PAK,D2PAK,TO-220-FP,TO-220

- 58 OPN's
- Current Vbr Range: 80V to 120V
- Current Io range: 20A to 40A

Trench Schottky Rectifier - Portfolio Expansion Summary

Current Portfolio:

- Count : 58 Orderable Part Numbers.
- VBr Range: 80 V to 120 V
- Io range: 20 A to 40 A
- Pkgs : TO-220/I2Pak/D2Pak/TO-220FP
- Type: Low Vf Only

Target Portfolio by 2H'14:

- Count : ?? Orderable Part Numbers
- VBr Range: 45 V to 200 V
- Io range: 1 A to 60 A
- New Pkgs : SMX/SO8FL/SOD123FL/SMAFL
- Type: Low Vf and Low Leakage

New Trends MOSFETs

New Trends – MOSFETS

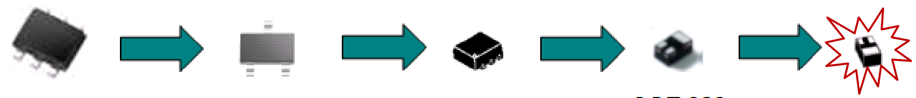
Features

- Small Footprint, down to 0.38mm²
- Ultra Thin Packages, 0.4mm
- 1.5V RDS(on) rating

Applications

- New Features Enable Switches
- Interface / Analog Switch
- Level Shift and Level Translate

Industry Smallest FETs

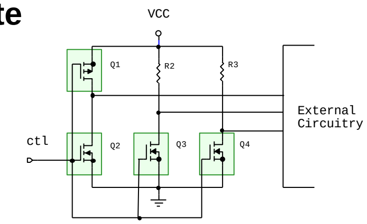


SOT-563	SOT-723	SOT-963	SOT-883	XLLGA
1.6x1.6x0.5mm	1.2x1.2x0.5mm	1.0x1.0x0.5mm	1.0x0.6x0.4mm	0.62x0.62x0.4mm
2.56mm ²	1.44mm ²	1.0mm²	0.6mm²	0.38mm²

End Products

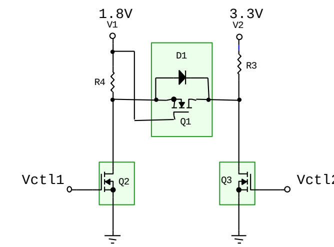
- Media Tablets and Smart Phones

Interface Switches



To connect to external interfaces with ultra high off resistance
The low gate drive voltage allows the use in ultra low voltage environment (<1.65V)

Level Translator



Logic levels can be translated in both directions

Part Number	Package	Dimensions mm	Configuration	Pol	Maximum Ratings VDS (V)	VGS (V)	ID (A)	PD (W)	RDS(on) Ω V_{GS} 4.5V	V_{GS} 2.5V	V_{GS} 1.8V	V_{GS} 1.5V	Sample Date	Release Date
NTNS3193NZ	XLLGA3	0.6x0.6x0.4	Single	N	20	±8	0.23	0.13	1.40	1.90	2.20	4.30	Now	Now
NTNS3A91PZ	XLLGA3	0.6x0.6x0.4	Single	P	-20	±8	0.21	0.13	1.60	2.40	3.30	4.50	Now	Now
NTNS3164NZ	SOT-883	1.0x0.6x0.4	Single	N	20	±8	0.22	0.13	1.50	2.00	3.00	4.50	Now	Now
NTNS3A65PZ	SOT-883	1.0x0.6x0.4	Single	P	-20	±8	0.23	0.13	1.60	2.40	3.40	4.50	Now	Now
NTNUS3171PZ	SOT-1123	1.0x0.6x0.4	Single	P	-20	±8	0.15	0.13	3.50	4.00	5.50	7.00	Now	Now
NTUD3170NZ	SOT-963	1.0x1.0x0.4	Dual	N	20	±8	0.22	0.13	1.50	2.00	3.00	4.50	Now	Now
NTUD3169CZ	SOT-963	1.0x1.0x0.4	Complementary	N	-20	±8	0.22	0.13	1.50	2.00	3.00	4.50	Now	Now
				P	20	±8	0.25	0.13	5.00	6.00	7.00	10.00		
NTK3139P	SOT-723	1.2x1.2x0.5	Single	P	-20	±6	0.78	0.45	0.48	0.67	0.95	2.20	Now	Now
NTK3134N	SOT-723	1.2x1.2x0.5	Single	N	20	±6	0.89	0.45	0.35	0.45	0.65	1.20	Now	Now
NTK3043N	SOT-723	1.2x1.2x0.5	Single	N	20	±10	0.26	0..45	3.40	4.50	10.00	15.00	Now	Now
SCH1342	SOT-563	1.6x1.6x0.56	Single	P	-12	±10	4.5	1.0	0.052	0.091	0.21	0.111	Now	Now
NTZS3151P	SOT-563	1.6x1.6x0.5	Single	P	-20	±8	0.9	0.21	0.142	0.200	0.240	-	Now	Now
NTZD3152P	SOT-563	1.6x1.6x0.5	Dual	P	-20	±6	0.4	0.25	0.900	1.200	2.000	-	Now	Now
NTZD3154N	SOT-563	1.6x1.6x0.5	Dual	N	20	±6	0.5	0.25	0.550	0.700	0.900	-	Now	Now
NTZD5110N	SOT-563	1.6x1.6x0.5	Dual	N	60	±20	0.3	0.25	2.500	-	-	-	Now	Now
NTZD3155C	SOT-563	1.6x1.6x0.5	Complementary	N	20	±6	0.54	0.25	0.550	0.700	0.900	-	Now	Now
				P	-20	±6	0.43	0.25	0.900	1.200	2.000	-		

Charging Circuit Solution – P Channel

Features

- Low RDS(on)
  - → Improve System Efficiency
- u8FL, uDFN and CPS packages
  - → Space Saving
  - → Excellent Thermal Conduction

End Products

- Media Tablets, Smart Phones, others

Applications

- Battery Switch
- Power Load Switch
- Over Voltage & Reverse Current Protection

u8FL
3.3x3.3x0.8mm

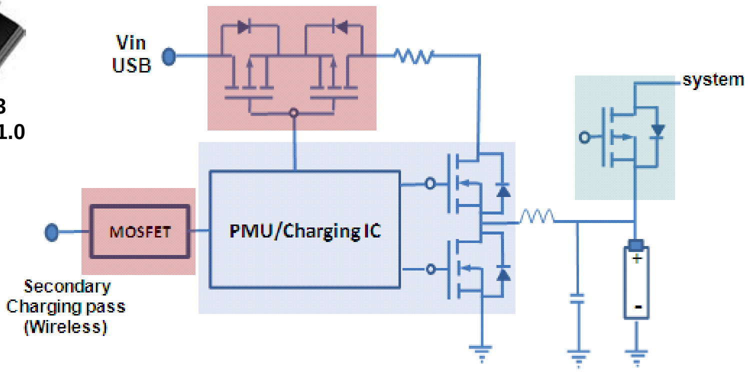
SC-88(ECH8)
2.0x2.1x0.75

SOT-23
2.9x2.4x1.0

UDFN
2.0x2.0x0.55

CSP
1.46x1.46x0.45

UDFN
1.6x1.6x0.55



Part Number	Package	Dimensions mm	Config.	Pol	Maximum Ratings						Samples	Release	Applications
					VDS (V)	VGS (V)	ID (A)	RDS(on) Ω					
								V_{GS} 4.5V	V_{GS} 2.5V	V_{GS} 1.8V			
EFC6301	CSP	1.46x1.46x0.44	Single	P	-12	±10	6	0.0215	0.026	0.035	Now	Q2-13	Battery Switch
NTLUS3C18PZ	UDFN	1.6x1.6x0.5	Single	P	-12	±10	6.4	0.025	0.035	0.065	Q1-13	Q3-13	Battery Switch
NTLUS3A39PZ	UDFN	1.6x1.6x0.5	Single	P	-20	±8	5.2	0.039	0.050	0.081	Now	Now	Battery Switch
NTLUD3A260PZ	UDFN	1.6x1.6x0.5	Dual	P	-20	±8	1.7	0.200	0.290	0.390	Now	Now	OV and Reverse Current Protection
NTLUS3C13PZ	UDFN	2.0x2.0x0.5	Single	P	-12	±10	10	0.0125	0.0175	0.0255	Q1-12	Q3-13	Battery Switch
NTLUS3A18PZ	UDFN	2.0x2.0x0.5	Single	P	-20	±8	8.2	0.018	0.025	0.05	Now	Now	Battery Switch
NTLUD3A50PZ	UDFN	2.0x2.0x0.5	Dual	P	-20	±8	4.5	0.048	0.07	0.115	Now	Now	OV and Reverse Current Protection
NTLUD3A75PZ	UDFN	2.0x2.0x0.5	Dual	P	-30	±12	4.5	0.075	0.097	0.125	Q3	Q4	OV and Reverse Current Protection
NTLJS3A18PZ	WDFN	2.0x2.0x0.8	Single	P	-20	±8	8.2	0.018	0.025	0.05	Now	Now	Battery Switch
MCH6351	SC-88	2.0x2.1x0.85	Single	P	-12	±10	9	0.017	0.019	0.04	Now	Q2-13	Battery Switch
NTR3A30PZ	SOT-23	2.9x2.4x1.0	Single	P	-20	±8	3.2	0.037	0.050	0.065	Now	Apr-13	Battery Switch
ECH8601	ECH8	2.9x2.8x0.9	Dual	P	-12	±10	9	0.015	0.02	0.029	Now	Q2-13	OV and Reverse Current Protection
NTTFS3A08PZ	µ8FL	3.3x3.3x0.8	Single	P	-20	±8	14	0.0067	0.09	-	Now	Now	Battery Switch

Switching MOSFET Roadmap Overview

2011

T2/T3 30V N-CH
SO8FL TE
Heatsinkable , High Power Density
Server/Netcom DC-DC

T3 HSVR/LSVR 30V N-CH
Asymmetric Dual SO-8FL and u8FL
High Efficiency Phase Pair, Min Layout
Computing (NB, Tablet) DC-DC

T3 w Schottky (LSVR) 30V N-CH
S08-FL and u8FL
High Efficiency Lowside
Computing (DT,NB)/Netcom DC-DC

2012

T3 HSVR/LSVR 30V N-CH
PhaseFET
High Eff Phase Pair, High Pwr Density
Server/Netcom DC-DC

2013

T6 30V N-CH
u8FL, S08-FL, Duals
Low Cost, Technology Upgrade
Computing (DT,NB) DC-DC

2014

T6 30V N-CH + Schottky
u8FL, S08-FL, Duals
High Performance/Efficiency
Server/Netcom DC-DC

Switching MOSFET Roadmap – Computing

NTMFD4901NF
30V/20V Dual N-CH, SO8FL
10Ω/3.5mΩ @4.5V, T3.1/T3.2

NTMFD4902NF
30V/20V Dual N-CH, SO8FL
10mΩ/6.2mΩ @4.5V, T3.1/T3.2

NTLLD4901NF
30V/20V Dual N-CH, WDFN8
30mΩ/22mΩ @4.5V, T3.1/T3.2

NTMD4903NF
30V/20V Dual N-CH, SO8
30mΩ/16mΩ @4.5V, T3.1/T3.2

NTMFS4983NF
30V/20V Single N-CH, SO8FL
3mΩ @4.5V, T3

NTMFS4985NF
30V/20V Single N-CH, SO8FL
5mΩ @4.5V, T3

NTTFS4985NF
30V/20V Single N-CH, µ8FL
5mΩ @4.5V, T3

NTMFS4C05N
30V/20V Single N-CH, SO8FL
5mΩ @4.5V, T6

NTMFS4C08N
30V/20V Single N-CH, SO8FL
8.3mΩ @4.5V, T6

NTMFS4C10N
30V/20V Single N-CH, SO8FL
10.6mΩ @4.5V, T6

NTMFS4C13N
30V/20V Single N-CH, SO8FL
13.5mΩ @4.5V, T6

NTTFS4C05N
30V/20V Single N-CH, µ8FL
5mΩ @4.5V, T6

NTTFS4C10N
30V/20V Single N-CH, SO8FL
10.6mΩ @4.5V, T6

NTTFS4C25N
30V/20V Single N-CH, µ8FL
25mΩ @4.5V, T6

NTMFD4C20N
30V/20V Dual N-CH, SO8FL
10.8mΩ/5.2mΩ @4.5V, T6

NTMFS4C06N
30V/20V Single N-CH, SO8FL
6mΩ @4.5V, T6

NTMFS4C09N
30V/20V Single N-CH, SO8FL
8.3mΩ @4.5V, T6

NTTFS4C06N
30V/20V Single N-CH, µ8FL
6mΩ @4.5V, T6

NTTFS4C08N
30V/20V Single N-CH, µ8FL
8.5mΩ @4.5V, T6

NTTFS4C13N
30V/20V Single N-CH, µ8FL
13.8mΩ @4.5V, T6

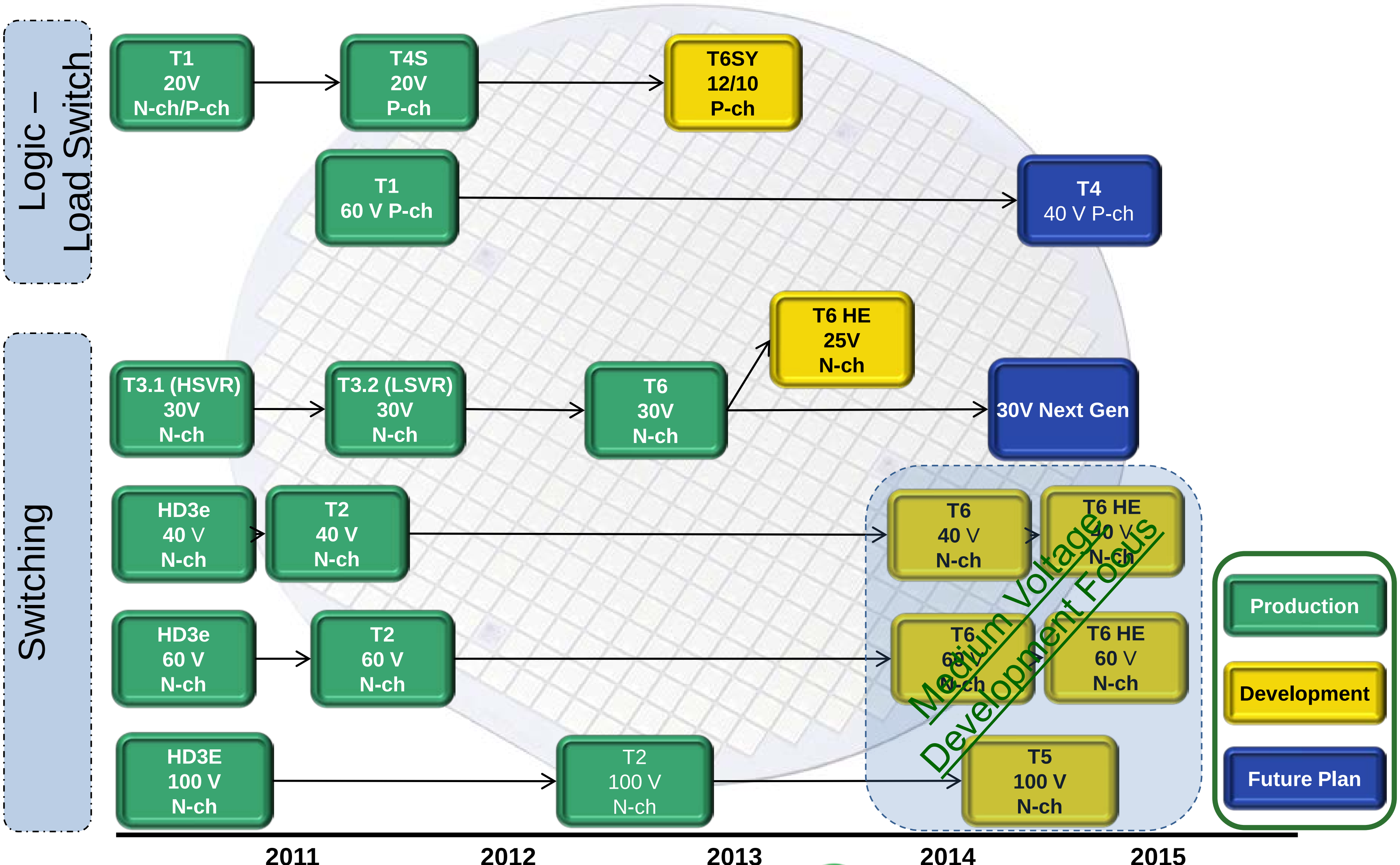
NTMFS4CXXNF
30V/20V Single N-CH + Int Sch, SO8FL

NTMFD4CXXNF
30V/20V Dual N-CH + Int Sch, Asym Dual

2012 2013 2014

Production	Development	Planning	Exploring

Low & Medium Voltage MOSFET Roadmap



Planned 40/60 V Industrial & Automotive MOSFETs

Features

- Best in-class FOM ($R_{DS(ON)}$ x Q_G)
- Low Q_G
- Low $R_{DS(ON)}$
- Soft switching
- Industry standard 5x6mm package

Benefits

- ➔ Increased efficiency, lower power dissipation
- ➔ Reduction in switching losses
- ➔ Reduction in conduction losses
- ➔ Reduced ringing and noise
- ➔ Standard footprint for direct drop-in

Applications

- Secondary Side Synchronous Rectification
- Diode ORing, Hot Swap, Battery Protection
- Motor Control, Load Switch, Solenoid Driver

Markets

- Motor Control
- Power Supply
- Automotive Engine, Chassis, Body Control

Part Number	Auto Standard Part Number	Package	Polarity	Config.	V_{DS} Max (V)	V_{GS} Max (V)	$R_{DS(on)}$ @4.5 V		$R_{DS(on)}$ @10 V		Q_G Typ @4.5 V (nC)
							Typ (mΩ)	Max (mΩ)	Typ (mΩ)	Max (mΩ)	
NTMFS5C404NL	NVMFS5C404NL	SO-8FL	N	Single	40	20	0.8	1.0	0.6	0.75	42
NTMFS5C418NL	NVMFS5C418NL	SO-8FL	N	Single	40	20	1.25	1.55	0.95	1.2	32
NTMFS5C442NL	NVMFS5C442NL	SO-8FL	N	Single	40	20	3.1	3.9	2.25	2.8	11
NTMFS5C604NL	NVMFS5C604NL	SO-8FL	N	Single	60	20	1.3	1.6	1.0	1.2	53
NTMFS5C612NL	NVMFS5C612NL	SO-8FL	N	Single	60	20	1.7	2.2	1.3	1.6	40
NTMFS5C646NL	NVMFS5C646NL	SO-8FL	N	Single	60	20	5.2	6.2	3.9	4.7	13

Planned 40/60 V High Speed Switching MOSFETs

Features

- Best in-class FOM ($R_{DS(ON)}$ x Q_G)
- Low Q_G
- Low $R_{DS(ON)}$
- Low Qoss
- Industry standard 5x6mm package

Benefits

- → Increased efficiency, lower power dissipation
- → Reduction in switching losses
- → Reduction in conduction losses
- → Increased efficiency in hard switching
- → Standard footprint for direct drop-in

Applications

- Primary Side Switch
- Secondary Side Synchronous Rectification
- Motor Control, Load Switch, Solenoid Driver

Markets

- Telecom, Datacom
- Base Station
- Power Supply

Part Number	Package	Polarity	Config.	V_{DS} Max (V)	V_{GS} Max (V)	$R_{DS(on)}$ @4.5 V		$R_{DS(on)}$ @10 V		Q_G Typ @4.5 V (nC)	Q_{OSS} Typ @1/2 V_{DS} Max (nC)
						Typ (mΩ)	Max (mΩ)	Typ (mΩ)	Max (mΩ)		
NTMFS5C401NL	SO-8FL	N	Single	40	20	0.8	1.0	0.6	0.75	42	73
NTMFS5C403NL	SO-8FL	N	Single	40	20	1.25	1.55	0.95	1.2	32	45
NTMFS5C407NL	SO-8FL	N	Single	40	20	3.1	3.9	2.25	2.8	11	20
NTMFS5C601NL	SO-8FL	N	Single	60	20	1.3	1.6	1.0	1.2	53	103
NTMFS5C603NL	SO-8FL	N	Single	60	20	1.7	2.2	1.3	1.6	40	79
NTMFS5C607NL	SO-8FL	N	Single	60	20	5.2	6.2	3.9	4.7	13	25

Planned 100 V MOSFETS

Features

- Best in-class FOM
- Lowest available Q_G
- Low $R_{DS(ON)}$
- Soft switching
- Industry standard 5x6mm package
- AEC-Q101 qualified

Benefits

- Increased efficiency, lower power dissipation
- Reduction in switching losses
- Reduction in conduction losses
- Reduced ringing and noise
- Standard footprint for direct drop-in
- Enables automotive opportunities

Applications

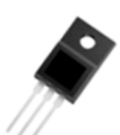
- Primary Side Switch
- Secondary Side Synchronous Rectification
- Diode ORing, Hot Swap, Battery Protection
- Solenoid Driver, PS Boost Switch

Markets

- Telecom, Datacom
- Base Station
- Power Supply
- Automotive Engine, Lighting Control

Part Number	Auto-Standard Part Number	Package	Polarity	Config.	V_{DS} Max (V)	V_{GS} Max (V)	$R_{DS(on)}$ @10 V		Q_G Typ @10 V (nC)	Q_{OSS} Typ @1/2 V_{DS} Max (nC)
							Typ (mΩ)	Max (mΩ)		
NTMFS6B03N	NVMFS6B03N	SO-8FL	N	Single	100	20	3.3	3.7	55	99
NTMFS6B05N	NVMFS6B05N	SO-8FL	N	Single	100	20	4.5	5	40	73
NTMFS6B10N	NVMFS6B10N	SO-8FL	N	Single	100	20	8.5	10	22	39
NTMFS6B14N	NVMFS6B14N	SO-8FL	N	Single	100	20	12	14	15	27
NTMFS6B25N	NVMFS6B25N	SO-8FL	N	Single	100	20	20	25	9	16

Today’s N-Channel “ND” Series – Product Offering

Package	Part Number	Package	Config	Pol	Maximum Rating				VGS(th) Min (V)	VGS(th) Max (V)	Qg (nC)	Ciss (pF)	Coss (pF)	Sample Availability	RTM
					VDS (V)	ID (A)	VGS (V)	RDS(ON) (mΩ)							
 DPAK (TO-252)	NDD02N40T4G	DPAK (TO-252)	Single	N	400	2	30	5500	0.8	2.0	10	125	15	Now	Now
	NDD03N50ZT4G	DPAK (TO-252)	Single	N	500	3	30	3300	3.0	4.5	10	274	38	Now	Now
	NDD04N50ZT4G	**DPAK (TO-252)**	**Single**	**N**	**500**	**4**	**30**	**2700**	**3.0**	**4.5**	**12**	**308**	**43**	**Now**	**Now**
	NDD05N50ZT4G	DPAK (TO-252)	Single	N	500	5	30	1500	3.0	4.5	19	530	68	Now	Now
	NDD01N60T4G	DPAK (TO-252)	Single	N	600	1	30	8500	2.2	3.7	6.5	160	22	Now	Now
	NDD02N60ZT4G	DPAK (TO-252)	Single	N	600	2	30	4800	3.0	4.5	10.1	274	34	Now	Now
	NDD03N60ZT4G	DPAK (TO-252)	Single	N	600	3	30	3600	3.0	4.5	12	312	39	Now	Now
	NDD04N60ZT4G	DPAK (TO-252)	Single	N	600	4	30	2000	3.0	4.5	19	535	62	Now	Now
	NDD03N80ZT4G	DPAK (TO-252)	Single	N	800	3	30	4500	3.0	4.5	17	440	52	Now	Now
 IPAK (TO-251)	NDD02N40-1G	IPAK (TO-251)	Single	N	400	2	30	5500	0.8	2.0	10	125	15	Now	Now
	NDD03N50Z-1G	IPAK (TO-251)	Single	N	500	3	30	3300	3.0	4.5	10	274	38	Now	Now
	NDD04N50Z-1G	**IPAK (TO-251)**	**Single**	**N**	**500**	**4**	**30**	**2700**	**3.0**	**4.5**	**12**	**308**	**43**	**Now**	**Now**
	NDD05N50Z-1G	IPAK (TO-251)	Single	N	500	5	30	1500	3.0	4.5	19	530	68	Now	Now
	NDD01N60-1G	IPAK (TO-251)	Single	N	600	1	30	8500	2.2	3.7	6.5	160	22	Now	Now
	NDD02N60Z-1G	IPAK (TO-251)	Single	N	600	2	30	4800	3.0	4.5	10.1	274	34	Now	Now
	NDD03N60Z-1G	IPAK (TO-251)	Single	N	600	3	30	3600	3.0	4.5	12	312	39	Now	Now
	NDD04N60Z-1G	IPAK (TO-251)	Single	N	600	4	30	2000	3.0	4.5	19	535	62	Now	Now
	NDD03N80Z-1G	IPAK (TO-251)	Single	N	800	3	30	4500	3.0	4.5	17	440	52	Now	Now
New  SOT-223 (TO-261)	NDT01N60T3G	SOT-223	Single	N	600	1	30	8500	2.2	3.7	6.5	160	22	Now	Now
	NDT02N40T3G	SOT-223	Single	N	400	2	20	5500	0.8	2.0	10	125	15	Now	Now
 TO-220FP	NDF05N50ZH	TO-220FP	Single	N	500	5	30	1500	3.0	4.5	18.5	530	68	Now	Now
	NDF08N50ZH	TO-220FP	Single	N	500	8	30	850	3.0	4.5	31	912	120	Now	Now
	NDF11N50ZH	TO-220FP	Single	N	500	11	30	520	3.0	4.5	46	1375	166	Now	Now
	NDF02N60ZH	TO-220FP	Single	N	600	2	30	4800	3.0	4.5	10.1	274	34	Now	Now
	NDF03N60ZH	TO-220FP	Single	N	600	3	30	3600	3.0	4.5	12	312	39	Now	Now
	NDF04N60ZH	TO-220FP	Single	N	600	4	30	2000	3.0	4.5	19	535	62	Now	Now
	NDF06N60ZH	TO-220FP	Single	N	600	6	30	1200	3.0	4.5	31	923	106	Now	Now
	NDF08N60ZH	TO-220FP	Single	N	600	8	30	950	3.0	4.5	39	1140	129	Now	Now
	NDF10N60ZH	TO-220FP	Single	N	600	10	30	750	3.0	4.5	47	1425	150	Now	Now

Super Junction Initial Target Products – U1 Series

- 600 V Products available Q3 2013
- 500 V Products available Q4 2013

Package	Part Number	Package	Config	Pol	Maximum Rating				VGS(th) Min (V)	VGS(th) Max (V)	Qg (nC)	Ciss (pF)	Coss (pF)
					VDS (V)	ID (A)	VGS (V)	RDS(ON) (mΩ)					
 DPAK (TO-252)	NDD50N320U1T4G	DPAK (TO-252)	Single	N	500	10	25	320	2.0	4.0	27	816	60
	NDD50N470U1T4G	DPAK (TO-252)	Single	N	500	7	25	470	2.0	4.0	19	547	42
	NDD50N630U1T4G	DPAK (TO-252)	Single	N	500	6	25	630	2.0	4.0	17	450	38
	NDD50N790U1T4G	DPAK (TO-252)	Single	N	500	5	25	790	2.0	4.0	14	364	33
	NDD60N360U1T4G	DPAK (TO-252)	Single	N	600	10	25	360	2.0	4.0	30	790	60
	NDD60N550U1T4G	DPAK (TO-252)	Single	N	600	6	25	550	2.0	4.0	19	540	44
	NDD60N745U1T4G	DPAK (TO-252)	Single	N	600	4	25	745	2.0	4.0	14	363	25
	NDD60N900U1T4G	DPAK (TO-252)	Single	N	600	4	25	900	2.0	4.0	14	363	25
	NDD60N1K8U1T4G	DPAK (TO-252)	Single	N	600	3	25	1800	2.0	4.0	10	190	13
 IPAK (TO-251)	NDD50N320U1-1G	DPAK (TO-252)	Single	N	500	10	25	320	2.0	4.0	27	816	60
	NDD50N470U1-1G	DPAK (TO-252)	Single	N	500	7	25	470	2.0	4.0	19	547	42
	NDD50N630U1-1G	DPAK (TO-252)	Single	N	500	6	25	630	2.0	4.0	17	450	38
	NDD50N790U1-1G	DPAK (TO-252)	Single	N	500	5	25	790	2.0	4.0	14	364	33
	NDD60N360U1-1G	DPAK (TO-252)	Single	N	600	10	25	360	2.0	4.0	30	790	60
	NDD60N550U1-1G	DPAK (TO-252)	Single	N	600	6	25	550	2.0	4.0	19	540	44
	NDD60N745U1T4G	DPAK (TO-252)	Single	N	600	4	25	745	2.0	4.0	14	363	25
	NDD60N900U1-1G	DPAK (TO-252)	Single	N	600	4	25	900	2.0	4.0	14	363	25
	NDD60N1K8U1-1G	DPAK (TO-252)	Single	N	600	3	25	1800	2.0	4.0	10	190	13

Part Numbering System

Part Numbering System - IGBTs

ROOT

N G T B 2 5 N 1 2 0 I H W T 4 G

Product Class
N = ON Semi Standard
S = Special
P = Engineering Proto

Product Group
GT = IGBT

Product Family
B =IGBT (with co-pack diode)
I = Intelligent power modules
P = Power Integrated Module
D = Die sale
G = IGBT Only

Current @ 100^{o}C in A

Polarity
N = N Channel
P = P Channel

Voltage [V/10]
60 = 600 V
90 = 900 V
120 = 1200 V
135 = 1350 V
140 = 1400 V
170 = 1700 V

Pb-Free Designator
G = Lead-Free

Optional Tape and Reel Suffix
T4 = DPAK/D2PAK

Package Designator (1 digit)
T = TO-3P
W = TO-247
B = D2PAK
D = DPAK
E = TO-220
F = TO-220FP
S = TO-264

Optional Performance Attributes (1 or 2 digits)
- Standard IGBT (≤20kHz)
F = FAST IGBTs (20kHZ – 50kHz)
U = Ultrafast IGBTs (50kHZ to 100kHz)
L = Field Stop
L2 = Field Stop Gen II
R = Reverse Conducting(monolithic)
S- = Special(S1, S2, S3…ect)
IH = Inductive Heating Optimized

Part Numbering System - MOSFETs

Low and Medium Voltage MOSFETs:

N T M F S 4 8 4 1 N T 4 G

Product Class
N = Standard
S = Special/Custom
X = Pilot Production
P = Engineering prototypes

Product Group
G = IGBT
M = Micro Integration
T = Power MOSFET
V = Automotive MOSFET

Package Designators
A	SC-75
B	D2PAK
C	Chip Sales
D	DPAK
E	SC-89
F	SOT-223
G	TSOP
H	ChipFET
J	SC-88
K	SOT-723
L	QFN/DFN/WDFN
M	SOIC-8
N	SOT-1123/SOT-883/XDFN/ULLGA
P	TO-220
Q	TSSOP
R	SOT-23
S	SC-70
T	Micro-8
U	SOT-963
V	FlipChip
W	TO-247
Y	TO-264
Z	SOT563

'A' after pkg designator = ICEPAK S1 footprint
'B' after pkg designator = ICEPAK SQ footprint
'C' after pkg designator = ICEPAK MT footprint
'D' after pkg designator = dual
'E' after pkg designator = ICEPAK MX footprint
'F' after pkg designator = fullpak
'K' after pkg designator = ICEPAK
'L' after pkg designator = leadless
'S' after pkg designator = single config
"F" after pkg designator = flat lead
"G" after pkg designator = >0.80 mm thick
"J" after pkg designator = 0.60 to 0.80 mm thick
"Q" after pkg designator = quad
"U" after pkg designator = <0.60 mm thick

Voltage Rating
1	< 1 to 8V
2	9 to 12 V
3	13 to 20 V
4	21 to 30 V
5	31 to 60 V
6	61 to 124 V
7	125 to 250 V
8	251 o 499 V
9	500 V +

G = Pb free plating / 260c
H = Halide free compound

Tape/reel designator
12MRH00360A
Preferred tape suffix refer Appendix O & P (EIA-481) suffix designation

Polarity/Other
A = Current Sense
B = Bidirectional
N = N Channel
P = P Channel
C = Complementary
F = Fetky
K = Temperature Sense
L = Logic Level
S = SenseFET
T = TVS
W = Wafer Pack
Z = ESD
E = Enhanced

Part Numbering System - MOSFETs

High Voltage MOSFETs:

N D D 1 2 N 3 4 Z T 4 G

- N — **Product Class**
  - N = Standard
  - S = Special/Custom
- D — **Product Group**
  - D = High Voltage MOSFET
- D — **Package Designator**
  - B = D2PAK (or I2PAK if with “-1” suffix)
  - D = DPAK (or IPAK if with ”-1” suffix)
  - F = TO-220FP/Fullpak
  - P = TO-220AB
- 1 2 — **Current Rating**
- N — **Polarity**
  - N = N-Channel
  - P = P-Channel
- 3 4 — **Voltage Rating (x10)**
- Z — **Optional Feature**
  - Z = Zener diode-protected gate
- T 4 — **Packaging Option**
  - <blank> = Rail
  - -1 = Straight-lead version
  - T4 = Tape/reel
  - **Preferred tape suffix refer Appendix O & P (EIA-481) suffix designation**
- G — **Pb-free Designator**
  - G = Lead-free

Thank You

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